**IEEE P802.15**

**Wireless Personal Area Networks**

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| Re: | draft text for inclusion into 802.15.8 |
| Abstract | This text defines a Sync frame and the process for forming and operating a PAC network using of the UWB PHY. |
| Purpose | This document provides the details text for the IEEE 802.15.8 draft |
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**PAC Networking with the UWB PHY**

***This document contains text for integration into the 802.15.8 draft***

1. MAC protocol
	1. MAC functional description

***Insert the following new clause in an appropriate place in the draft, maybe as the final sub-clause of the MAC functional description….***

* + 1. PAC networking with the UWB PHY
			1. Introduction

While the UWB PHY may be used for data communications, its unique utility is its support of accurate two-way ranging and localization. Recognizing that there are applications for UWB only PAC networks, where the primary use case is peer-to-peer relative location or relative positioning, this clause describes the formation and operation of UWB only PAC networks to facilitate these applications.

PAC networking with just the UWB PHY has some differences to the scheme employed with the Low and High Mobility OFDM PHYs. In particular, three features of the UWB PHY require a different approach:

* Firstly, the UWB PHY does not have a special synchronization sequence. Instead, a MAC Sync frame is defined.
* Secondly, the UWB PHY cannot support the multi-carrier grids that are used for conveying discovery information and negotiating CFP usage. Instead, the Sync frame carries the discovery information and a CFP usage indication used to cooperate on CFP usage.
* Thirdly, the UWB PHY does not support carrier-sensing CCA, which means that procedures like the OFDM synchronization scheme that employ CSMA-CA need to be done differently for the UWB PHY with its ALOHA channel access mechanism.

For operating a PAC network using UWB PHY, the MAC sync frame defined in 5.2.3.1 is employed for synchronization, to convey discovery information, and to cooperate on CFP usage within the superframe. The support of this process, (herein called the cooperative synchronization process), and Sync frame is optional for a PD that supports PHY other that the UWB PHY, but is mandatory for a PD that supports only the UWB PHY.

The formation and operation of a PAC network using the UWB PHY is described sub-clauses 5.1.1.2 to 5.1.1.8. The use of UWB for ranging in an established non-UWB PAC network is described in 5.1.1.9.

* + - 1. The superframe structure

For standalone UWB use, the superframe structure is organized as shown in Figure 1. With an overall duration of *aSuperframeDuration*, the UWB superframe is divided into three periods: the UWB Sync Period of length *aUwbSyncPeriodDuration*, the UWB CAP of length *aUwbCapDuration* and the UWB CFP of length *aUwbCfpDuration*.



**Figure 1—The UWB superframe structure**

The UWB Sync Period is used for sending sync frames, as described in 5.1.1.3. The CAP shall be used for peering and other MAC procedures and may be employed for general application initiated data communication and ranging. The CFP shall only be used for application initiated data communication & ranging.

* + - 1. Sending sync frames

The UWB Sync Period is divided into eight equal length Sync Slots. The MAC shall randomly choose which of these Sync Slots to use when it is sending a sync frame. Sync Slots are numbered 0 to 7 in sequence, with Sync Slot 0 being the first in time. In addition, the starting time within the Sync Slot is randomly delayed by one of the four delays specified in Table 1. The selected delay code, from Table 1, and the selected Sync Slot number are encoded in the Sync frame’s Sync Control field described in 5.2.3.1.3.

**Table 1—UWB symbol delays for Sync frame transmission**

|  |  |
| --- | --- |
| **Start time delay code** | **Delay value in preamble symbol times** |
| 0b00 | 0 |
| 0b01 | 2.25 |
| 0b10 | 4.5 |
| 0b11 | 6.75 |

In the BPM-BPSK modulation mode, the Sync frames shall be sent with a preamble of 128 symbols, the SFD with sequence ID (b) as defined in Table 121, the PHR defined in 10.1.3.1, and the PSDU at the 6.81 Mb/s nominal modulation rate.

In the OOK modulation mode, the Sync frames shall be sent with a preamble of 8 symbols, the PHR defined in 10.1.3.1, and the PSDU at 437 kb/s nominal modulation rate, and the Sync Period and CAP durations shall be *aUwbOokSyncPeriodDuration* and *aUwbOokCapDuration*.

*<In the two paragraphs above, for the “Table 121” reference please insert the correct hyperlinked cross-reference to the table titled “BPM-BPSK modulation SFD sequences”, and, for the two “10.1.3.1” references please insert correct hyperlinked cross-references to the clause titled “PHR for frames up to 127 octets”>.*

* + - 1. The cooperative synchronization process

Where a number of PDs want to form a PAC network using the UWB PHY, this process allows the PDs to synchronize their communications, discover each other and, form groups that can operate independently in a cooperative fashion so that they do not interfere with each other.

The upper layer initiates the cooperative synchronization process by issuing the MLME-COSYNC.request primitive, defined in 6.1.1.1. The upper layer may also issue this primitive, while the PD is already operating the cooperative synchronization process, to update any of the various parameters of the process, or to stop it.

In summary, the process consists of:

* The new PD turning on its receiver to listen for Sync frames and aligns to superframe if any are received. The PD notes any discovery information provided by the received Sync frames along with the other information about CFP and CAP usage, and peering being accepted.
* After finding other PD sending Sync frames, the new PD may begin sending its own Sync frames with discovery information, advertising its presence and readiness to accept peering requests. Alternatively, it may just continuing monitoring the sync period without sending its own Sync frames, but waiting to receive Sync frames from a PD with whom it is interested in peering. The PD may initiate peering with any PD sending Sync frames that advertise a willingness to accept peering.
* Where the PD does not receive any sync frames from other PD it may begin sending its own Sync frames, or it may discontinue the cooperative synchronization process and issue the MLME-COSYNC.confirm primitive, defined in 6.1.1.2 to inform the upper layer of the failure to synchronize with another PD.

The details of the operation are described in the following sub-clauses.

* + - * 1. Achieving initial synchronization

Subsequent to the receipt of the MLME-COSYNC.request primitive from the upper layer, the cooperative synchronization process begins with the PD listening continuously for Sync frames from already sending PDs for a period of up to *macCosyncInitialListenPeriod*. If a Sync frame is received, the PD shall align itself to the superframe boundary, receiving any subsequent Sync frames being sent by other PD in any remaining slots of the current Sync period, and if *macSendSyncFrames* is TRUE, begin sending its own Sync frames starting in the next superframe period.

If no Sync frames are received within the *macCosyncInitialListenPeriod* listening period, then if *macSendSyncFrames* is FALSE the PD shall issue the MLME-COSYNC.confirm primitive indicating this failure and shall set *macCosyncActive* to FALSE. Otherwise, i.e. when *macSendSyncFrames* is TRUE, the PD shall start sending Sync frames, as per 5.1.1.3, defining its own superframe and sync period, transmitting in a randomly selected sync slot and monitoring the other sync slots to receive Sync frames from other PDs. The PD may turn its receiver off during the remainder of the superframe to save power, but once every *macCosyncLongListenInterval*, (where this is non-zero), it shall turn on its receiver for an entire superframe period to look for other PD’s Sync frames. When a lone unsynchronized PD receives a Sync frame from other PDs it shall align its superframe with the superframe of the other PDs.

* + - * 1. Maintaining synchronization

The PAC network synchronization is maintained by each PD behaving as follows:

When a PD is sending Sync frames, it shall send a Sync frame once per superframe period in a randomly chosen Sync Slot as defined in 5.1.1.2 and 5.1.1.3, and shall turn on its receiver to receive sync frames in all the other Sync Slots of the UWB Sync Period. The PD shall adjust its Sync frame transmission time with respect to the arrival times of any Sync frames received in earlier Sync Slots of the Sync Period.

When a PD is not sending Sync Frames, (i.e. *macSendSyncFrames* is FALSE), but is participating in the cooperative synchronization process, (i.e. *macCosyncActive* is TRUE), it shall continue to turn on its receiver during Sync Period to receive Sync frames, and maintain its alignment with the superframe boundary.

* + - * 1. Resolving overlap of separate networks

Since PAC networks are mobile, a group of PDs in synchronization may encounter another group of PDs that are also in synchronization among themselves, but where the superframes of the two groups are not aligned with a result that the overlap may give rise to mutual interference between the groups.

To remove the mutual interference the groups need to be synchronized to a common superframe alignment. To reduce the overall level of disruption it is desirable that the group with fewer PDs moves to align with the superframe of group with more PDs.

The detection of misaligned overlapping groups occurs when a PD synchronized with other PDs sending Sync frames in the Sync Period receives a Sync frame in another part of the superframe. A measure of the fullness of the newly encountered group may be ascertained from the Local PD Density Indication (LPDI) carried in the Sync frame. The detecting PD shall then decide which group is the denser and select it as the *target superframe* that maintains its alignment, and the other less dense group is then the *misaligned superframe* that needs to move alignment. The detecting PD shall temporarily participates in both alignments, sending Sync frames in each with the following characteristics:

* In the misaligned superframe, the detecting PD shall send sync frames with the superframe misalignment detected (SMD) field set to one, and the Resync field set to one indicating that the superframe misalignment correction (SMC) field is present giving the offset to the target alignment. The fields DIP, CUP, CAPTX, CAPRX and AP shall be set to zero, so that no CFP usage or Discovery Information is carried by the Sync frame. A PD receiving a sync frame with SMD and Resync fields set to one, shall use the SMC field to realign its superframe boundaries, and shall discontinue any active CFP usage and the indication of this in its transmitted Sync frame, until it has assessed the CFP usage in the new expanded group and re-selected appropriate CFP for its needs.
* In the target superframe, the detecting PD shall send sync frames with the superframe misalignment detected (SMD) field set to one. The Resync field shall be set to zero indicating no realignment is necessary. The LPDI shall be set to reflect an estimate of the density of the merged group. If the detecting PD has already been participating in the target superframe then the other fields of the Sync frame shall be unaltered. If the detecting PD is moving from the misaligned superframe then it shall discontinue any active CFP usage and the indication of this in its transmitted Sync frame, until it has assessed the CFP usage in the new expanded group and re-selected appropriate CFP for its needs. A PD receiving a sync frame with the SMD field set to one, and the Resync field set to zero is thus made aware that additional PDs are present and will be aligning with its superframe and potentially contending for CFP resources.

This sending of Sync frames with SMD set to one shall continue for *macSmdSyncFrameDuration* superframes after which the detecting PD shall cease sending Sync frames in the miss aligned superframe, and shall set SMD to zero in any Sync frames it sends in the aligned superframe.

* + - * 1. Moving to use another complex channel

A complex channel is the combination of physical radio RF channel selection and a preamble sequence selection. In general, when two PAC networks are operating on different complex channels they will have a low level of mutual interference.

Where a set of PDs operating in a PAC network are peered in a closed group, (i.e. a group with no need or intention to expand or accept additional peering from any potential new members), this set of PDs is essentially autonomous. The closed group benefits from participating in the cooperative synchronization process since it enhances its coexistence with other PDs, but the closed group could easily move to operate on a different complex channel.

In the case where the number of synchronized PDs sharing the air or the CFP usage grows towards full capacity, it could be beneficial for a closed group to move to another channel that is less crowded. The LPDI in received Sync frames may be used by the upper layers to judge the level of air-utilization as part of any decision to move complex channel, or, where two sets of PDs need to merge their synchronization (as per 5.1.1.5) this event may precipitate the decision for the closed group to choose to move to a different complex channel.

The selection of a new complex channel is achieved through the setting of the *phyCurrentChannel* and *phyUWBPreambleCode* PIB attributes.

The decision and control of moving the closed group to operate on another complex channel, and the complex channel selection, is a function of the upper layers to agree and inform all members of the closed group to move to the new complex channel at an agreed time. The mechanisms for doing this are out of scope of this standard.

* + - 1. Discovery and peering

The upper layer uses the MLME-COSYNC.request primitive to specify, to the MLME, the content to send in the Sync frame. This content includes the discovery information, the PD’s intention to receive in the CAP and its willingness to peer with other PDs. Upon receipt of each Sync frame, the MLME passes this content to the upper layer via an MLME-COSYNC.indication primitive. The upper layer may initiate peering through the MLME-PEERING.request if it wishes to peer with any of the discovered PDs.

The message interaction for peering (and any other MAC procedures defined in this standard) shall take place during the CAP.

* + - 1. Non-interfering closed sub-groups (for UWB ranging)

One application scenario consists of sets of PDs forming closed groups for the purposes of ranging solely among their respective groups. In this scenario, the cooperative synchronization process ensures that the groups mutually synchronize their activity so that they do not interfere with each other, as each uses some of the available CFP for its ranging interactions. While this is upper layer functionality, it is described here to illustrate the operation of the cooperative synchronization process in a real use case. For each closed group, one PD may take the lead sending the Sync frames defining the timing and CFP usage for the group.

The simplest example is a group of just two PDs that might operate as follows: The lead PD sends the sync frames initially with discovery information to allow the second PD to detect and peer with the lead PD. Once peering is achieved, the lead PD may omit the discovery information from its Sync frame to save power. The lead PD then indicates its CFP usage in the Sync Frame. This defines when the ranging exchange should occur, the lead PD upper layer then issues the MLME-RECEIVER-ENABLE.request to turn the receiver in the selected slot while the second PD upper layer issues the MCPS-DATA.request to transmit the frame initiating the ranging exchange. The ranging interaction proceeds according to one ranging procedures defined in 12.4 *<insert correct hyperlinked cross-reference to this clause titled “Ranging procedures”>*. When the lead PD is sending a response frame to the second PD this response may include the Interaction Time Adjustment IE, defined in 5.2.4.4.2, to inform the second PD to adjust the transmission time of its ranging initiation frame for the next interaction. This allows the second PD to save power by not receiving the lead PD’s Sync frame for the next superframe interaction.

* + - 1. Using the CFP

MLME issue the MLME-COSYNC.indication primitive to report Sync frame reception events the cooperative synchronization process. An MLME-COSYNC.indication shall be issued for each Sync frame received during the Sync Period. The upper layers wishing to use the CFP may note the information about CFP usage over a period, (i.e. collating a number of MLME-COSYNC.indication reports), and choose unused portions of the CFP to suit its application needs. The upper layer uses the MLME-COSYNC.request primitive to indicate the intended CFP usage to the MLME, which shall include it in the CFP Usage field of its transmitted Sync frames.

At least one PD member of a group that is communicating using the CFP shall transmit Sync frames that include the CFP usage, typically this PD will be the one that is notionally leading or hosting the group. Depending on the application, and how its group control of peering and membership operates temporally, more than one PD in a group may indicate the group’s CFP usage in its Sync frames. This is an operational matter for the upper layer application and out of the scope of this standard to specify.

* + - 1. Ranging with UWB in an established (non-UWB) PAC network

The operation of UWB ranging in established (non-UWB) PAC network is under the control of the higher layers in each PD wishing to participate in ranging. The PD applications wishing to perform a ranging exchange will need to agree on the mode of operation of the UWB PHY including all necessary parameters for successful communication and ranging (e.g. mode, channel, preamble code or DPS choices, etc.). They will also need to agree on the roles each will take in the ranging exchange and the timing of the exchange, that is, who will initiate the exchange by transmitting the first UWB message at the appropriate time and who will be the responder turning on their UWB receiver at the appropriate time to await the ranging initiation message. The mechanisms to achieve this agreement are beyond the scope of this standard, but could be made by prior agreement or negotiated via data exchanges through the non-UWB PAC network connections.

At the appropriate agreed times, the upper layers in each PD operate to configure and appropriately enable the UWB PHY, perform the ranging exchange following the procedures defined in clause 12 *<insert correct hyperlinked cross-reference to this clause titled “Relative positioning and localization”>*, and then return to non-UWB operation subsequent to the ranging exchange.

To avoid this ad-hoc UWB ranging interfering unduly with any established UWB PAC networks that may be in the vicinity, the preamble code used shall be chosen randomly from the supported set of preamble codes, excluding the one nominated in 5.1.3.1 for the UWB common mode, which is reserved as the default for UWB PAC networking. In addition, the following procedures shall be used depending on the frequency of this ad-hoc UWB ranging.

* + - * 1. Infrequent ad-hoc UWB ranging

This is ranging that is performed occasionally, e.g. once every few minutes. In this case, there is no need to attempt to synchronize with any active UWB PAC networks, and the exchange can just be performed. However, if the exchange fails, or is retired and fails more than a couple of times, then this might indicate that there is an active UWB PAC network nearby that is causing a conflict, in which case the approach of 5.1.1.9.2 is more appropriate, or alternatively a different complex channel could be agreed upon by the upper layers, and tried.

* + - * 1. More frequent ad-hoc UWB ranging

This is ranging that is performed more often, perhaps once every few seconds. In this case, the PD shall attempt to synchronize with any UWB network present by turning on the UWB receiver to listen for UWB Sync frames for up to *aSuperframeDuration*. If a Sync frame is received, the PD shall execute the UWB ranging exchange in the CAP part of the UWB superframe, randomly picking a starting place consistent with finishing the exchange before the end of the CAP. For subsequent ranging exchanges, the UWB PHY receiver can be enabled appropriately, (i.e. consistent with the worst-case clock drift since the last attempt), to receive another Sync frame to align the exchange with the CAP. If no Sync frames are received, the ranging exchange can be performed at any time as per 5.1.1.9.1.

* + - * 1. Very frequent ad-hoc UWB ranging

This is ranging that is performed every couple of seconds or more frequently than that. At the lower end of this frequency range, the PD shall attain synchronization as per 5.1.1.9.2, and then turn on its UWB receiver sufficiently often to receive UWB Sync frames from, and maintain synchronization with, any UWB network present in the vicinity and continue to use the CAP as per 5.1.1.9.2. At the higher end of this frequency range, or where the PD wishes to use the CFP for the ranging exchange, it shall fully follow the cooperative synchronization process and use the CFP as per 5.1.1.8 for the ranging exchanges.

* 1. MAC frame formats
		1. PD addresses
		2. General MAC frame format

***Modify Table 4 “Values of the Frame Type field” in clause 5.2.2.1.1 to include the sync frame as follows…***

**5.2.2.1.1 Frame type field**

The Frame Type field shall be set as defined in Table 4

**Table 4—Values of the Frame Type field**

|  |  |
| --- | --- |
| **Frame type valueb3 b2 b1 b0** | **Description** |
| 0000 | ~~Reserved~~ Sync |
| 0001 | Data |
| 0010 | Acknowledgment |
| 0011 | MAC command |
| 0110to 1111 | Reserved |

* + 1. Format of individual frame types

***Add new clause “5.2.3.1 Sync frame format” before existing clause “5.2.3.1 Data frame format”***

* + - 1. Sync frame format (for use with the UWB PHY)

The Sync frame is used in the formation and operation of a PAC network using the UWB PHY as described in 5.1. The Sync frame shall be formatted as illustrated in Figure 2.

 

**Figure 2—Sync frame format**

* + - * 1. Sync frame MHR field

The Frame Type field shall contain the value that indicates a Sync frame. The DAM field shall indicate a broadcast frame with no destination address. The SAM field shall indicate that a full 48-bit PD MAC source address is present. The AR/SNS filed shall indicate that the Sequence number field is suppressed (and acknowledgement is not requested).

* + - * 1. Sync frame IEs

No currently defined IE is relevant to the Sync frame. Nonetheless, a PD receiving a sync frame shall be able to correctly parse the IEs fields (and ignore them if irrelevant) if their presence is indicated in the Frame Control field.

* + - * 1. Sync Control field

The Sync Control field shall be formatted as illustrated in Figure 3.



**Figure 3—Format of the Sync Control field**

The Sync Type field shall be b000.

The Sync Position field and Sync Delay Code field shall be set to the Sync Slot Number and Sync Delay Code values randomly selected for the transmission of the Sync frame, as defined in 5.1.1.3.

The Discovery information present (DIP) field shall be set to one to indicate the presence of the Group ID and Application ID fields. If the Group ID and Application ID fields are not included in the Sync frame, the DIP field shall be zero.

The CFP Usage Present (CUP) field shall be set to set to one to indicate the presence of the CFP Usage field. If the Application ID field is not included in the Sync frame, the CUP field shall be zero.

The CAPTX field shall be set to one when the PD intends to initiate a transmission in the CAP of the current superframe. If CAPTX is zero, the PD may still transmit in the CAP in response to the reception of a frame. The CAPTX field may be used by other PD to prompt them to turn on their receivers in the CAP if they are interested in communications from the sending PD.

The CAPRX field shall be set to one to indicate that PD intends to turn on its receiver to listen for frames in the CAP of the current superframe. If CAPRX is zero, the PD may still receive in the CAP, i.e. the PD may still turn on its receiver to await an acknowledgement or other response to some frame it has just sent in the CAP. The CAPRX field is intended to let other PD know that this PD will be listening to receive any unsolicited frames they may want to send to it.

The AP field shall be set to one to indicate that PD is open to accept peering requests in the CAP of the current superframe. When AP is one, the CAPRX field shall also be set to one.

The superframe misalignment detected (SMD) field and the Resync field are used to indicate and resolve the situation where two groups of PD operating with separate superframe alignment encounter each other. This usage is described in 5.1.1.5.

* + - * 1. CFP Usage field

If present, the CFP Usage field shall convey the intended usage of the CPF of the current and/or subsequent superframes by the sending PD, or by the group whose activity the sender is leading. The CFP Usage field shall be formatted as illustrated in Figure 4.

 

**Figure 4—Format of the CFP Usage field**

The CFP Usage field consists of three sub-fields: the CFP slot usage (CSU) bitmap, the CFP frequency of occupancy (CFOO) field and the countdown to next use (CTNU) field.

The CSU bitmap shall have a one-to-one concordance with the slots of the CFP. That is, bit-0 of the CSU bitmap corresponds to the usage of the first in time CFP slot, and bit-31 of the CSU bitmap corresponds to the final CFP slot. Where a bit in the CSU bitmap is set to a binary one, it indicates that the PD (or the group it is leading) intends to use the corresponding CFP slot, with the occupancy defined by the CFOO and CTNU fields.

The CFOO and CTNU occupancy defining fields facilitate the possibility sharing the same CFP area among different uses where the free capacity allows it.

The CFOO field is copied from the PDs *macCfpUseFrequency* PIB attribute. This indicates the frequency of usage of the CFP. It specifies the number of unused superframes between each use of the CFP by the PD. To ease using spare capacity the values this may take shall be limited to the options given in Table 2.

The CNTU field specifies the countdown in superframes until the next usage of the CFP. The value is copied from the PDs *macCfpUseCountdown* PIB attribute. This shall be a number between 0 and the CFOO value. A CNTU value of zero means that the CFP usage is occurring in the CFP of the current superframe (i.e. the one carrying the Sync frame indication a CNTU value of zero).

**Table 2—Allowed values for CFP frequency of occupancy (CFOO) field**

| **CFOO value** | **Frequency of usage (Hz)** |
| --- | --- |
| 0 | 10.000 |
| 1 | 5.000 |
| 2 | 3.333 |
| 3 | 2.500 |
| 4 | 2.000 |
| 7 | 1.250 |
| 9 | 1.000 |
| 11 | 0.833 |
| 14 | 0.667 |
| 15 | 0.625 |
| 19 | 0.500 |
| 24 | 0.400 |
| 29 | 0.333 |
| 39 | 0.250 |
| 49 | 0.200 |
| 99 | 0.100 |

The values of the CSU bitmap, CFOO and CTNU fields are set by the upper layers via the MLME-COSYNC.request primitive.

The *macCfpUseCountdown* value shall be decremented by one after each sync frame transmission, modulo *macCfpUseFrequency* + 1, so that decrementing the value of zero shall result in the *macCfpUseCountdown* value being set equal to the *macCfpUseFrequency* value for the next transmitted Sync frame.

* + - * 1. PAC Network Density Indication (LPDI) field

The Local PD Density Indication (LPDI) field gives a measure of the fullness of the air from the point of view of the sending PD. The LPDI field is present in the Sync frame when the Resync field (within the Sync Control field) is zero, otherwise (when the Resync field is set) the LPDI field is replaced with the superframe misalignment correction (SMC) field described in 5.2.3.1.6. The LPDI has two uses:

* Alignment: If two unaligned PAC networks encounter each other, the lower density network aligns to higher density network’s superframe.
* Avoidance of interference: It can inform a decision to use another channel/preamble code, i.e. a group leader may decide to move the group to another channel / preamble code selection.

The LPDI field shall be formatted as illustrated in Figure 5.

 **Figure 5—Format of the LPDI field**

The LPDI shall be assessed over a period of *aLapiAssessmentPeriod* seconds. Each PD sending Sync frames shall assess the LPDI to update the sub-fields of the LPDI field every *aLapiAssessmentPeriod* seconds. The sub-fields of the LPDI are defined below.

The estimated number of PDs sending Sync frames (ENPSS) gives a measure of how many other PDs are in the vicinity sending Sync frames. This is a simple count over the *aLapiAssessmentPeriod*, saturating at a maximum value of 31.

The CAP usage indicator (CAPUI) is a 3-bit field giving the PD’s view of the percentage of PDs utilizing the CAP based on the prevalence of CAPTX and CAPRX indications in the received Sync frames and the PD’s own CAP usage. The CAPI value range meanings are listed in Table 3.

**Table 3—CAPUI field meanings**

| **CAPUI value** | **100% of PDs using the CAP** |
| --- | --- |
| 0 | < 12.5% |
| 1 | >= 12.5% and < 25% |
| 2 | >= 25% and < 37.5% |
| 3 | >= 37.5% and < 50% |
| 4 | >= 50% and < 62.5% |
| 5 | >= 62.5% and < 75% |
| 6 | >= 75% and < 87.5% |
| 7 | >= 87.5%  |

The CFP fullness indicator (CFPFI) gives PD’s view of the level of utilization of the CFP based on the CFP usage data from received Sync frames and its own CFP usage. See 5.2.3.1.4 for details of the CSU bitmap and the CFOO sub-fields that indicate individual PD’s CFP usage. The CFPFI shall have a value in the range from 0x00 to 0xFF, where 0x00 means the CFP is free and 0xFF means that it is fully used.

* + - * 1. Superframe misalignment correction (SMC) field

The superframe misalignment correction (SMC) field indicates the offset between misaligned superframes, which is used as part of resolving the situation where two groups of PD operating with separate superframe alignment encounter each other. This usage is described in 5.1.1.5. The SMC field is present when the Resync field (within the Sync Control field) is one; otherwise, this field is replaced by the LPDI field described in 5.2.3.1.5.

The value of the SMC field is a single 16-bit unsigned integer value computed by subtracting the most recent start of the target superframe from the start of the misaligned superframe, (i.e. as indicated by the misaligned Sync Frame received in the CAP or CFP). The result is expressed in units of 2 µs. The valid range to cover the full size of a superframe is then 0 to 50,000.

* + - * 1. Group ID field

If present, the Group ID field shall convey the group identifier supplied by the upper layer in the MLME-COSYNC.request primitive.

* + - * 1. Application ID field

If present, the Application ID field shall convey the application identifier supplied by the upper layer in the MLME-COSYNC.request primitive.

* + 1. Information Elements (IEs)
			1. Payload IEs

***Modify Table 11 “Class 0 Payload IEs” in clause 5.2.4.4 to add new IE with ID of 8, and Table 12 “Class 1 Payload IEs” to add new IE with ID of 0 as follows…***

**Table 11—Class 0 Payload IEs**

|  |  |  |  |
| --- | --- | --- | --- |
| **Class 0 Payload IE ID** | **IE Description** | **Acronym** | **Sub-clause** |
| 0 | Payload IE list terminator. | - | 5.2.4.2 |
| 1 | Ranging Request Reply Time IE | RRRT IE | 12.2.3.1 |
| 2 | Ranging Reply Time Instantaneous IE | RRTI IE | 12.2.3.2 |
| 3 | Ranging Reply Time Deferred IE | RRTD IE | 12.2.3.3 |
| 4 | Ranging Preferred Reply Time IE | RPRT IE | 12.2.3.4 |
| 5 | Ranging Control Double-sided TWR IE | RCDT IE | 12.2.3.5 |
| 6 | Ranging Round Trip Measurement IE | RRTM IE | 12.2.3.6 |
| 7 | Ranging Time-of-Flight IE | RTOF IE | 12.2.3.7 |
| 8 | Interaction Time Adjustment IE | ITA IE | 5.2.4.4.2 |
| ~~8~~ 9 to 15 | Reserved |  |  |

**Table 12—Class 1 Payload IEs**

|  |  |  |  |
| --- | --- | --- | --- |
| **Class 1 Payload IE ID** | **IE Description** | **Acronym** | **Sub-clause** |
| 0 | Interaction Period Specification IE | IPS IE | 5.2.4.4.1 |
| ~~0~~ 1 to 511  | Reserved | - | - |

***Add the two new sub-clauses below at the end of clause 5.2.4.4 (describing the IEs added to tables 11 and 12 :***

* + - * 1. Interaction Period Specification IE

The Interaction Period Specification IE (IPS IE) is used to inform a PD (in a unicast frame) or a group of PD (in a multicast group addressed frame) where their interaction should occur in the superframe. This may be used by a group leader (as described in 5.1.1.7) to tell individual participating PD where their particular interaction should occur within the CFP slot(s) selection. The content field of the IPS IE shall be formatted as shown in Figure 6.

|  |  |
| --- | --- |
| **Octets:2** | **Variable** |
| Position | Control |

**Figure 6—Interaction Period Specification IE Content field format**

The IPS IE’s Position field is an unsigned 16-bit integer that specifies, in units of 2 µs, where the interaction is to occur with respect to the start of the superframe. The IPS IE’s Control field is an application specific value (perhaps a role or an ordinal value) that is meaningful in the context of the parities participating in the interaction.

* + - * 1. Interaction Time Adjustment IE

The Interaction Time Adjustment IE (ITA IE) is by one PD to convey the offset between the arrival time of a frame received from the addressed PD and the expected arrival time of the frame. This may be used by a group leader (as described in 5.1.1.7) to tell a participating PD that its next transmission time needs the specified adjustment. The content field of the ITA IE shall be formatted as shown in Figure 7.

|  |  |
| --- | --- |
| **Octets:2** | **Variable** |
| Adjustment | Control |

**Figure 7—Interaction Time Adjustment IE Content field format**

The ITA IE’s Adjustment field is a signed 16-bit integer giving value in units of 2 µs. A positive adjustment value indicates that the received frame was early by this time, (or exactly on time for a zero value). A negative adjustment value indicates that the received frame was late by this time. The receiving PD can use this value to adjust its interactions in subsequent superframes. The ITA IE’s Control field is an application specific value meaningful in the context of the parities participating in the interaction.

***Add the new sub-clauses below to define the primitives used in the cooperative synchronization process:***

1. MAC services
	1. MLME-SAP primitives
		1. Primitives for cooperative synchronization (for use with the UWB PHY)

These primitives are used for the cooperative synchronization process described in 5.1.1.4.

* + - 1. MLME-COSYNC.request

This primitive allows the next higher layer to control the enablement of the cooperative synchronization process, described in 5.1.1.4. The semantics of this primitive are:

MLME-COSYNC.request (

 CosyncControl,
 InitialListenPeriod,
 LongListenInterval,

SendSyncFrames,

 SendDiscoveryInfo,

 DiscoveryGroupId,

DiscoveryAppId,

SendCfpUsage,

CfpUseBitmap,

CfpUseFreq,

CfpUseDownCount,

SetCapTxFlag,

SetCapRxFlag,

AcceptingPeering,

)

The primitive parameters are defined in Table 4.

Table 4— MLME-COSYNC.request parameters

| **Name** | **Type** | **Valid range** | **Description** |
| --- | --- | --- | --- |
| CosyncControl | Enumeration | COSYN\_START,COSYN\_STOP | Specify whether the upper layer wants to start or stop the process.  |
| InitialListenPeriod |  Integer | 0 to 255 | Number of superframe periods for which the PD shall initially listen for sync frames before beginning to send its own sync frames.  |
| LongListenInterval | Integer  | 0 to 255 | Interval in superframe periods, defining how often the PD will listen for a complete superframe period looking for sync frames. A value of 0 means no listening, 1 means listen every superframe, 2 means listen every second superframe, etc. The process described in 5.1.1.4. |
| SendSyncFrames | Boolean | TRUE, FALSE | Determines whether the PD should send sync frames or just passively detect them. |
| SendDiscoveryInfo | Boolean | TRUE, FALSE | Parameter to control the inclusion of the group ID and application ID discovery information in the transmitted Sync Frame. |
| DiscoveryGroupId | Integer | 0x0000 to 0xFFFF | The Group ID to include in the transmitted Sync frame when the SendDiscoveryInfo parameter is TRUE. |
| DiscoveryAppId | Array | 13 octets, each 0 to 255 | The Application ID to include in the transmitted Sync frame when the SendDiscoveryInfo parameter is TRUE. |
| SendCfpUsage | Boolean | TRUE, FALSE | Determines whether the Sync frame includes the CFP usage indication parameters: CfpUseBitmap, CfpUseFreq and CfpUseDownCount. |
| CfpUseBitmap | Integer | 0 to 0xFFFFFFFF | Bitmap indicating CFP slot usage, which shall be included in the transmitted Sync frame, in the Sync frame CFP Usage field, (as described in 5.2.3.1.4), if the SendCfpUsage parameter is TRUE. |
| CfpUseFreq | Unsigned integer | Allowed values are defined in Table 2. | Value indicating how often the slots indicated in the CfpUseBitmap parameter are used. This shall be included in the transmitted Sync frame, in the Sync frame’s CFP Usage field, (as described in 5.2.3.1.4), if the SendCfpUsage parameter is TRUE. |
| CfpUseDownCount | Unsigned integer | 0 to CfpUseFreq | Countdown in superframes until the next usage of the CFP. This value shall be included in the transmitted Sync frame’s CFP Usage field, (as described in 5.2.3.1.4), if the SendCfpUsage parameter is TRUE. |
| SetCapTxFlag | Boolean | TRUE, FALSE | Specify whether the CAPTX flag in the transmitted Sync frame’s Sync Control Field is to be set or clear. |
| SetCapRxFlag | Boolean | TRUE, FALSE | Specify whether the CAPRX flag in the transmitted Sync frame’s Sync Control Field is to be set or clear. |
| AcceptingPeering | Boolean | TRUE, FALSE | Specify whether the AP flag in the transmitted Sync frame’s Sync Control Field is to be set or clear. |

* + - * 1. When generated

This primitive is generated by the next higher layer to request that the MLME begins or ends the cooperative synchronization process, and to update the Sync frame content or other parameters associated with the cooperative synchronization process.

* + - * 1. Effect on receipt

When the MLME receives the MLME-COSYNC.request primitive, if the cooperative synchronization process is not supported or is not supported by the *phyCurrentPage*, then the MLME-COSYNC.confirm primitive shall be issued indicating the failure of the request. Otherwise, the MLME-COSYNC.request primitive shall be handled as follows:

If the CosyncContol parameter is COSYN\_STOP any active the cooperative synchronization process shall be stopped, and the *macCosyncActive* PIB attribute shall be set to FALSE.

If the CosyncContol parameter is COSYN\_START, then the cooperative synchronization process, described in 5.1.1.4, shall be initiated and the *macCosyncActive* PIB attribute shall be set to TRUE. If the cooperative synchronization process is already active when an MLME-COSYNC.request primitive is issued with the CosyncContol parameter value of COSYN\_START, the cooperative synchronization process shall continue, but shall revise its operation according to the parameters being supplied, (e.g. updating the discovery info being sent according to the DiscoveryInfoControl and related discovery info parameters).

Parameter LongListenInterval shall be copied to the *macCosyncLongListenInterval* PIB attribute.

Parameter InitialListenPeriod and LongListenInterval parameters, shall be copied to the *macCosyncInitialListenPeriod* and *macCosyncLongListenInterval* PIB attributes.

Parameter SendSyncFrames shall be copied to the *macSendSyncFrames* PIB attribute.

If parameter SendCfpUsage is TRUE the value conveyed by the CfpUseBitmap shall be employed in the next and subsequent Sync frame transmissions. In addition, parameters CfpUseFreq and CfpUseDownCount shall be copied to the *macCfpUseFrequency* and *macCfpUseCountdown* PIB attributes. If the CfpUseFreq is not an allowed value, as defined in Table 2 or CfpUseDownCount is out of range then the MLME-COSYNC.confirm primitive shall be issued indicating the error.

The activities of the MAC / PD when the cooperative synchronization process is active are defined in 5.1.1.4.

Irrespective of the values conveyed by SetCapTxFlag, SetCapRxFlag, or the parameters defining for the CFP usage, the upper layers shall be responsible for invoking the MLME-RECEIVER-ENABLE.request primitive to turn on the receiver, and using the appropriate primitive to initiate MLME procedures or data transmissions at the appropriate times.

* + - 1. MLME-COSYNC.confirm

This primitive is issued to the next higher layer in response to an MLME-COSYNC.request primitive to report the result of the attempt to enable the cooperative synchronization process, described in 3.1.4. The semantics of this primitive are:

MLME-COSYNC.confirm (

 Status

)

The primitive parameters are defined in Table 5.

Table 5—MLME-COSYNC.confirm parameters

|  |  |  |  |
| --- | --- | --- | --- |
| **Name** | **Type** | **Valid range** | **Description** |
|  Status |  Enumeration | COSYNC\_NOT\_SUPPORTED,COSYNC\_ACTIVATED,COSYNC\_DEACTIVATED,COSYNC\_PARAM\_ERROR | The result of the request to enable or disable the receiver. |

* + - * 1. When generated

This primitive is generated by the MLME and issued to its next higher layer in response to an MLME-COSYNC.request primitive.

A status value of COSYNC\_NOT\_SUPPORTED shall be reported if the cooperative synchronization process is not supported or is not supported by the phyCurrentPage,

A status value of COSYNC\_ACTIVATED shall be reported if the MLME-COSYNC.request primitive resulted in the initiation or continuance of the cooperative synchronization process.

A status value of COSYNC\_DEACTIVATED shall be reported if the MLME-COSYNC.request primitive resulted in the deactivation of the cooperative synchronization process.

A status value of COSYNC\_PARAM\_ERROR shall be reported if the MLME-COSYNC.request primitive parameters CfpUseFreq and CfpUseDownCount values are not allowed.

* + - * 1. Effect on receipt

The upper layer is made aware of the result of its MLME-COSYNC.request primitive.

* + - 1. MLME-COSYNC.indication

This primitive is issued to the next higher layer to report Sync frame reception events the cooperative synchronization process, described in 5.1.1.4. The semantics of this primitive are:

MLME-COSYNC.indication (

SourceAddress,

DiscoveryInfoPresent,

DiscoveryGroupId,

DiscoveryAppId,

CfpUsagePresent,

CfpUseBitmap,

CfpUseFreq,

CfpUseDownCount,

CapTxFlag,

CapRxFlag,

AcceptingPeering,

LpdiValue

)

The primitive parameters are defined in Table 6.

Table 6—MLME-COSYNC.indication parameters

| **Name** | **Type** | **Valid range** | **Description** |
| --- | --- | --- | --- |
| SourceAddress | MAC Address | 48-bit value | This is the ID of the PD who sent the Sync frame. |
| DiscoveryInfoPresent | Boolean | FALSE, TRUE | Indicates whether the received Sync frame contained discovery information.  |
| DiscoveryGroupId | Integer | 16-bit value | This is the Group ID part of the discovery information contained in the received Sync frame. This parameter is only valid if the DiscoveryInfoPresent parameter is TRUE. |
| DiscoveryAppId | Array | 13 octets, each 0 to 255 | This is the Application ID part of the discovery information contained in the received Sync frame. This parameter is only valid if the DiscoveryInfoPresent parameter is TRUE. |
| CfpUsagePresent | Boolean | FALSE, TRUE | Indicates whether the received Sync frame contained a CFP Usage field. |
| CfpUseBitmap | Integer | 0 to 0xFFFFFFFF | Bitmap indicating CFP slot usage extracted from the received Sync frame. This parameter is only valid if the CfpUsagePresent parameter is TRUE. |
| CfpUseFreq | Unsigned integer | Expected values are defined in Table 2. | Value extracted from the received Sync frame indicating how often the slots defined by the CfpUseBitmap parameter are used. This parameter is only valid if the CfpUsagePresent parameter is TRUE. |
| CfpUseDownCount | Unsigned integer | 0 to CfpUseFreq | Value extracted from the received Sync frame indicating the remaining countdown (in superframes) until the next usage of the CFP by the Sync frame sender (or its group). This parameter is only valid if the CfpUsagePresent parameter is TRUE. |
| CapTxFlag | Boolean | FALSE, TRUE | Indicates the status of the CAPTX as carried by the Sync Control field of the received Sync frame. |
| CapRxFlag | Boolean | FALSE, TRUE | Indicates the status of the CAPTX as carried by the Sync Control field of the received Sync frame. |
| AcceptingPeering | Boolean | FALSE, TRUE | Indicates the status of the CAPTX as carried by the Sync Control field of the received Sync frame. |
| LpdiValue | Unsigned integer | 0x0000 to 0xFFFF | This gives the value LDPI field of the received Sync frame, see 5.2.3.1.5 for its definition. |

* + - * 1. When generated

While the cooperative synchronization process is active, this primitive is generated by the MLME and issued to its next higher layer each time a Sync frame is received during the Sync Period.

* + - * 1. Effect on receipt

The upper layer is made aware of the reception of the Sync frame and the respective parameters it conveys. It is expected that the upper layer will use this information to decide about its activity. That is the upper layer may use the discovery information and the CapRxFlag and AcceptingPeering values to decide to initiate peering with the PD identified by SourceAddress. The upper layer may use the LpdiValue and CFP usage information to decide about its own CFP usage, or any move to operate on another complex channel..

* 1. MAC Data Service
	2. PAC information base (PIB)

***Add the new PIB attribute and constant definitions below to the appropriate places in Table 73 “PIB attributes” and Table 74 “PAC constants”***

*Modify “Table 73—PIB attributes” to add the following new attributes:*

Attributes marked with a dagger (†) are read-only attributes (i.e. the attribute can only be set by the MAC sublayer).

Table 7—PIB fields

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Field** | **Type** | **Range** | **Default** | **Description** |
| *macCosyncInitial-ListenPeriod* |  Integer | 1 to 255 | 3 | Number of superframe periods for which the PD shall initially listen for sync frames before beginning to send its own sync frames.  |
| *macCosyncLong-ListenInterval* | Integer  | 0 to 255 | 0 | Interval in superframe periods, defining how often the PD will listen for a complete superframe period looking for sync frames. A value of 0 means no listening. |
| *macSendSync-Frames* | Boolean | TRUE, FALSE | FALSE | Determines whether the PD should send sync frames or just passively detect them. |
| *macCosyncActive*† | Boolean | TRUE, FALSE | FALSE | Indicates whether the cooperative synchronization process is active or disabled. |
| *macSmdSync-FrameDuration* |  Integer | 1 to 31 | 5 | The number of superframes for which a PD detecting misaligned groups shall send sync frames with the SMD field set to one. See 5.1.1.5 for details of the alignment process. |
| *macCfpUse-Frequency* | Integer | See Table 2 | 0 | This specifies the number of unused superframes between each use of the CFP by the PD. This value comes from the MLME-COSYNC.request. |
| *macCfpUse-Countdown* | Interger | 0 to *macCfpUse-Frequency*  | 0 | This is the countdown to the next use of the CFP by the PD. This value is set by the MLME-COSYNC.request but updated after each Sync frame transmission. |

*Modify “Table 73—PAC constants” to add the following new entries:*

Table 74—PAC constant table

| **Constant**  | **Description** | **Value** |
| --- | --- | --- |
| *aLapiAssessmentPeriod* | The time in seconds over which a PD sending Sync frames assesses the complex channel it is using to generate the LAPI field in its Sync Frame.  | 5 |
| *aUwbSyncPeriodDuration* | The duration in ms of the UWB synchronization period in the BPM-BPSK modulation mode. | 4 |
| *aUwbCapDuration* | The duration in ms of the UWB CAP in the BPM-BPSK modulation mode. | 24 |
| *aUwbCfpDuration* | The duration in ms of the UWB CFP. | 72 |
| *aUwbOokSyncPeriodDuration* | The duration in ms of the UWB synchronization period in the OOK modulation mode. | 12 |
| *aUwbOokCapDuration* | The duration in ms of the UWB CAP in the OOK modulation mode. | 16 |

**<END>**