**IEEE P802.15**

**Wireless Personal Area Networks**

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| Re: |  | |
| Abstract | This is the draft version of 802.15.8 PAC Framework Document. | |
| Purpose | This document provides the framework from which the draft PAC specification will be developed. The document provides an outline of each the functional blocks that will be a part of the final specification. The document is intended to reflect the working consensus of the group on the broad outline for the draft specification. As such it is expected to begin with minimal detail reflecting agreement on specific techniques and highlighting areas on which agreement is still required. It may also begin with an incomplete feature list with additional features added as they are justified. The document will evolve over time until it includes sufficient detail on all the functional blocks and their inter-dependencies so that work can begin on the draft specification itself. | |
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# Overview

The 802.15.8 specification shall be developed according to the P802.15.8 Peer Aware Communication (PAC) project authorization request (PAR), document number 15-12-0063r2 and Five Criteria (5c), document number 15-12-0064r1, which were approved by the IEEE-SA in March of 2012.

This standard defines PHY and MAC mechanism for Wireless Personal Area Networks (WPAN) Peer Aware Communications (PAC) optimized for Peer-to-Peer and infrastructure-less communications with fully distributed coordination. A peer can participate in multiple services or applications.

Key features of PAC may include the following:

* Operational in selected globally available unlicensed/licensed bands below 11 GHz capable of supporting these requirements
* Scalable data transmission rates, typically up to 10 Mbps
* Discovery for peer information without association
* Discovery signaling rate typically greater than 100 kbps
* Discovery of the number of devices in the network
* Group communications with simultaneous membership in multiple groups, typically up to 10
* Multi-hop relay
* Relative positioning
* Security

# Definitions

**Device ID**: Unique PAC device ID, e.g. MAC address

**Discovery information**: One or more of Device ID, Device Group ID, Application type ID, Application-specific ID, Application-specific user ID, and Application-specific group ID, and/or peer context and application-driven information

**Discovery**: Discovery is the procedure to detect existence and discovery information of other PDs that are within discoverable range.

**Discovering PD**: A PD which tries to discover other PD(s)

**Discovered PD**: A PD of which discovery information is received by a discovering PD.

**Peer aware communications (PAC) network**: A peer-to-peer wireless proximity network of which a device or devices communicate with other device(s) with various information such as configuration or control, location, sensing data, advertisement, multimedia contents, social contents, etc.

**Payload data**: contents of a data message that is being transmitted

# Abbreviations and acronyms

AGC Automatic Gain Control

CAP contention access period

CCA clear channel assessment

CFP contention free period

CP Cyclic Prefix

CS Channel Sampling

CTS Clear To Send

CW Contention Window

FCS Frame Check Sequence

GI Guard Interval

IS Interference Sensing

LTF Long Training Field

MLME MAC sublayer Management Entity

MLSDE MAC sublayer Service Discovery Entity

OFDM Orthogonal Frequency Division Multiplexing

PAN Personal Area Network

PD PAC Device

PDU Protocol Data Unit

PID Peering Identifier

Peering-REQ Peering-Request

Peering-RSP Peering-Response

PLME PHY layer Management Entity

RTS Request To Send

SC Single Carrier

SDU Service Date Unit

STF Short Training Field

ULA Uniform Linear Array

ZC Zadoff-Chu

BPSK binary phase-shift keying

CRC cyclic redundancy check

FEC forward error correction

LFSR linear feedback shift register

LSB least significant bit

MAC medium access control

MSB most significant bit

PHR PHY header

PHY physical layer

PPDU PHY protocol data unit

PRBS pseudo-random binary sequence

PSD power spectral density

PSDU PHY service data unit

RF radio frequency

SHR synchronization header

SYNC synchronization

UWB ultra wide band

# General descriptions

This clause provides the basic framework of PDs. The framework serves as a guideline in developing the functionalities of PDs and their interactions specified in detail in the subsequent clauses.

## Concepts and architecture

PAC provides functionalities optimized for scalable peer to peer communications with fully distributed coordination for decentralized system composed of PDs. PAC also provides mechanisms that enable low power consumption, discovery of peer information before association, efficient resource allocation in a distributed manner, and coexistence with other 802 systems.

Some PDs may be able to connect to infrastructure on an opportunistic basis, which is out of scope for IEEE 802.15.8.

****

A PAC system may contain the following functions at MAC and/or PHY. The block diagram is provided as an information only.

**Upper Layer:** the layer above PHY/MAC, such as middleware, and application layer.

**PD Management Entity:** manages PD information across PHY/MAC and upper layer for PAC communications.

**Synchronization Function:** performs initial and/or periodic time synchronization among PDs; maintains frequency and clock phase synchronization.

**Discovery Function:** discovers peer(s) in proximity by using discovery information**.**

**Peering Function:** requests or responds to Peering (i.e. association), Peering Updates, De-peering, or Re-peering.

**Channel Management Function:** manages the radio resource including channel allocation and/or access.

**Power Control Function:** performs transmit power control and interference management based on power control information.

**Measurement and Report Function:** conducts measurements of channel information, and sends data reports from other logic functions to upper layer.

**Scheduler Function:** manages or controls the sequence of events in MAC and/or PHY layer, for example, transmission queuing, collision avoidance, etc.

**Encoder Function:** performs encoding and other data processing such as interleaving, scrambling, etc. at PHY to aid in reliable reception

**Modulator Function:** performs modulation and other data processing such as mapping, precoding, etc. at PHY

**Decoder Function:** performs decoding and other data processing, such as de-interleaving, de-scrambling, etc. at PHY to aid in reliable reception

**Demodulator Function:** performs demodulation and other data processing such as equalization, de-mapping, etc. at PHY

## Topology

Several topologies, such as mesh topology or star topology, may be used to support interactions among PDs for various services. One-to-one and one-to-many topologies shall be supported.

IEEE 802.15.8 shall support a PD having simultaneous communication sessions for same or different applications. IEEE 802.15.8 shall support a PD participation in at least two independent communication sessions with different peers at the same time.

PAC supports multi-hop relay of at least two hops.



Figure 4.3. An example of concurrent communication

## Reference model

All services and functions of PDs are partitioned into a physical (PHY) layer and a medium access control (MAC) sublayer of the data link layer, in accordance with the ISO/OSI-IEEE Std 802-2001 reference model. Direct communications between PDs are to transpire at the PHY layer and MAC sublayer as specified in this standard; Message security services are to occur at the MAC sublayer, and security operations are to take place inside and/or outside the MAC sublayer.

Within a PD, the MAC provides its service to the upper layer through the MAC service access point (SAP) located immediately above the MAC sublayer, while the PHY provides its service to the MAC through the PHY SAP located between them. On transmission, the upper layer passes MAC service data units (MSDUs) to the MAC sublayer via the MAC SAP, and the MAC sublayer passes MAC frames (also known as MAC protocol data units or MPDUs) to the PHY layer via the PHY SAP. On reception, the PHY layer passes MAC frames to the MAC sublayer via the PHY SAP, and the MAC sublayer passes MSDUs to the upper layer via the MAC SAP.

MAC and PHY SAPs also pass control information between the layers.



Figure 2. Reference model

There may be a logical PD management entity (PDME) that exchanges network management information with the PHY and MAC as well as with other layers.

# MAC layer

* 1. Overview

This section defines MAC mechanism for Wireless Personal Area Networks (WPAN) Peer Aware Communications (PAC) optimized for peer-to-peer and infrastructure-less communications with fully distributed coordination.

The MAC functions are described in this clause. The following are main functions and their brief explanation.

* Synchronization is the procedure to establish and maintain synchronization, including at least reference timing, among PDs.
* Discovery is the procedure to find existence and discovery information of other PDs that are within discoverable range.
* Peering is the procedure to establish a link between a pair of PDs or links among multiple PDs.
* Communication is the procedure to exchange data or control/management message among PDs.

## Frame Structure

PAC operates in synchronization mode, where PDs share timing reference with other PDs in proximity.

The radio resource is comprised of successive synchronization intervals with fixed time duration. The length of the synchronization interval is for further study. A synchronization interval is divided into slots as illustrated in Figure S1.



**Figure S1:** Synchronization interval

Timing reference signals are transmitted in the Synchronization slot. Every synchronization interval shall include a synchronization slot.

Discovery, peering, and/or data communication slot is used for discovery, peering, and/or data communication. The discovery, peering, and/or data communication slot can be further divided into smaller slots. Different combinations of the smaller slots may be used to form different types of synchronization intervals to satisfy the requirements for discovery, peering, and data communication.

Figure S2 illustrates an example configuration of a synchronization interval, where the discovery, peering, and/or data communication slot is divided into discovery slot, peering slot, and data communication slot. The configuration of synchronization interval illustrated in Figure S2 provides a power saving feature by allowing PDs in sleep mode to sleep during data communication slot while staying active during the synchronization slot, discovery slot, and the peering slot.



**Figure S2: An example configuration of synchronization interval**

## Synchronization

In synchronized mode, PAC operates in fully distributed synchronization.

PAC currently recognizes two slightly different definitions of fully distributed synchronization.

* [Def. 1] Synchronization among PDs can be achieved by transmitting/receiving synchronization reference signal. When there is already synchronization among PDs, each PD may send synchronization reference signal independently to maintain the synchronization. When there is no synchronization already established, a PD can initiate it by transmitting synchronization reference signal.
* [Def. 2] Synchronization among PDs can be achieved by transmitting/receiving synchronization reference signal. The synchronization reference signal may be transmitted by a single PD dynamically elected by a group of PDs. When there is no synchronization already established, a PD can initiate it by transmitting synchronization reference signal.

## Discovery

PAC should support three discovery types of the following:

* Advertisement: In Advertisement type discovery, a PD broadcasts its own discovery information and does not expect responses.
* Publish/Subscribe: In Publish/Subscribe type discovery, a PD broadcasts its own discovery information and expects responses from PDs that have discovered the broadcast message.
* Query/Reply: In Query/Reply type discovery, a PD broadcasts the discovery information of the PD or PDs being queried and expects a response or responses from the PD or PDs, accordingly.

For the purpose of discovery of PDs, the discovery information may represent one or more of the following IDs such as Device ID, Device Group ID, Application type ID, Application-specific ID, Application-specific user ID, and Application-specific group ID.

The discovery procedure should support mechanisms to ensure privacy that a PD is not tracked.

The discovery procedure should support protection of identity from impersonation.

## Peering

Peering is the procedure to establish a link between a pair of PDs or links among multiple PDs discovered during the discovery procedure.

Re-peering is the procedure to re-establish a link between a pair of PDs or links among multiple PDs which peered previously. In the re-peering procedure, peering may be simplified.

De-peering is the procedure to disconnect the link established by peering.

**Peering Procedure**



Figure: Peering Procedure

The peering procedure is initiated by sending a peering request message including requested peering information. Responder may send a peering response message to requestor for indicating if the peering request is accepted or not. The response message may include peering information if the request is accepted.

**Re-peering procedure:**



Figure: Re-peering Procedure

Re-peering procedure is similar to peering procedure. The main differences are: 1) some of the previous peering information may not be included in request and response messages; 2) the PD receiving the request validates peering information before making a decision to accept the re-peering request.

**De-peering procedure:**



Figure: De-peering Procedure

De-peering procedure starts with a de-peering request, which is replied by a de-peering response message. De-peering response may be optional

## Communications

Data communication may be conducted as unicast between a pair of PDs, or as multicast within a group of PDs, or as broadcast to any PD.

### Unicast

Unicast is a one-to-one data communication between a pair of PDs. For reliable unicast transmission, ACK may be used for acknowledging a successful data transmission.

### Multicast

Multicast is a one-to-many data communication to a group or groups of PDs which may be addressed by an ID specific to the group or by multiple IDs. To support multicast, the following features are supported:

* Multicast Group Creation: A PD is able to create a multicast group if necessary.
* Joining multicast group: A PD is able to join a multicast group or multiple multicast groups in order to communicate with multicast group members.
* Leaving multicast group: A PD is able to leave a multicast group or multiple multicast groups to stop communication with multicast group members.

Reliable multicast is to provide reliable data transmission in multicast from one PD to multiple or all PDs with a group. For reliable multicast transmission, ACK may be used for acknowledging a successful multicasting.

****

**Figure: Distributed One-Hop Multicast**

### Broadcast

Broadcast is a one way data communication to any PDs within reachable range, or any PDs in a group. A PD which received a broadcast message does not respond with acknowledgement.



## MPDU structure















MPDU consists of MAC header, a variable length frame body, and a fixed length FCS. MAC header comprises data frame type, device IDs, service type IDs, MCS, MPDU length, and other information about the MPDU. Frame body is data information. FCS contains CRC check sequence for error detection.



Figure. PAC MPDU format

## Multiple access

Multiple access schemes allow multiple terminals to share a communication medium. For PAC standard, contention-based as well as contention-free multiple access schemes are under consideration.

In a contention-based multiple access scheme, multiple terminals compete for channel access. Examples of contention-based channel access schemes are Aloha protocol, and CSMA/CA. While contention-based access schemes tend to be simpler, channel access is not guaranteed and depends on probability.

Contention-free multiple access schemes try to guarantee channel access to devices so that the devices do not have to compete for channel access. It is usually easier to provide QoS provisioning with contention-free multiple access schemes, but they require coordination and scheduling among multiple devices.



## Synchronization procedure

Key desired features of synchronization procedure are as follows:

* Synchronization defined herein is for finding the time boundary either at PHY or at MAC. The time boundary may be symbol, slot, frame, application frame, super frame, etc.
* Synchronization reference signal may be a sequence or a beacon, e.g. a beacon for a frame and a sequence for a slot.
* All PDs should have the capability of sending or receiving a synchronization reference signal.
* Any PD should be able to synchronize with a PD or PDs in at least the discovery radio range, i.e. synchronized with neighboring PDs.
* There is no specific and static synchronization reference PD operating in a centralized manner, i.e. there is no dedicated PD for sending synchronization reference signal like a coordinator in a centralized control system.
* Synchronization mechanism should be designed to support low duty cycling for discovery and peering, i.e. low overhead for discovery and peering.
* Synchronization mechanism should be designed to efficiently support PDs participating in one or multiple group communications.
* Synchronization mechanism should be designed to efficiently support multi-hop communications.

IEEE802.15.8 PAC operates in synchronization mode. For PAC standard, three synchronization schemes are under consideration. In an arbitrary order, the three synchronization schemes are as follows:

* Distributed synchronization in PHY layer: PDs participating in the synchronization procedure transmit timing reference signal, which is received by neighbouring PDs. Upon receiving timing reference signals, a PD estimates the arrival time of the timing reference signals to adjust its own timing. Eventually, all PDs participating in the synchronization procedure converge to common reference timing.
* Distributed synchronization with time-stamp: PDs participating in the synchronization procedure transmit timing reference signal with time-stamp, which is received by neighbouring PDs. Upon receiving a timing reference signal, a PD estimates the arrival time of the timing reference signal which is used together with the time-stamp to adjust its own timing. Eventually, all PDs participating in the synchronization procedure will share common reference timing.
* Initiator based synchronization: A PD initiates synchronization by start to transmit timing reference signal. Neighbouring PDs adjust their own timing to the timing of the PD that initiated the synchronization. The PD that initiates the synchronization is elected by a group of PDs.

## Discovery procedure

Key desired features of peer discovery procedure:

* Peer discovery function is enabled or disabled triggered by upper layer.
* Peer discovery information is driven from upper layer.
* Peer discovery message comprises peer discovery information and peer discovery control. (Q: Do we want to discuss which control?)
* Peer discovery message can reflect the changes of services or requests from specific application. (???, For further discussion)
* A PD starts peer discovery broadcasting when peer discovery function is enabled. A PD transmits peer discovery message periodically during peer discovery broadcasting. A PD stops peer discovery broadcasting when peer discovery function is disabled.























































## QoS

The MAC sublayer provides the resource allocation features and the data primitives for supporting multiple grades of service to the next higher layer. The grades of service are categorized with the technical attributes specified in the application matrix for IEEE 802.15.8 (15-12-0684-00-008).

## Interference management

*Editor: The text below enclosed by <377r0> is general in nature, but needs some improvement.*

*Shannon?*

**<377r0 name=”Shannon, Samsung”>**

Interference among multiple links is managed by threshold level which is used to identify neighboring PDs. The number of concurrent link goes many as the threshold level goes low. Conversely, the number of concurrent link goes small as the threshold level goes high.

**</377r0>**

## Transmit power control

***Qing****, can you provide a high level general text on transmit power control from Distributed D2D point of view to replace the text below?*

## Multi-hop operation

To extend the coverage of a PD or group, a PD or a group relays received data to the destination PD or group. To support multi-hop operation, a PD or group members maintain a routing table.

## Relative positioning

A PD may measure the relative position of other PDs. The relative position data may be used for discovery of a PD, regulation of transmit power, or searching for a route to a PD or a group.

## Power management

*Editor:* ***Qing?***

## Security

Security layer provides users with privacy, authentication, and authorization across the network.

### Security modes

PAC security layer provides three different security modes on the basis of security requirements of network connections.

#### Security mode 1 (non-secure)

When a PAC device is in security mode 1, it shall never initiate any security procedure.

#### Security mode 2 (service level enforced security)

When a PAC device is in security mode 2, it shall initiate security procedures after a channel establishment request has been received or a channel establishment procedure has been initiated by itself. Whether a security procedure is initiated or not depends on the security requirements of the requested channel of service.

A PAC device in security mode 2 should classify the security requirements of its services using the following attributes.

|  |  |
| --- | --- |
| Security requirement | Description |
| Authentication required | - Before connecting to the application, the remote device must be authenticated |
| Authorization required | - Access is only granted automatically to trusted PAC devices, or untrusted devices after an authorization procedure  - Always requires authentication to verify that the device is the right one |
| Encryption required | - The link must be changed to encrypted mode, before access to the service is possible |

Security mode 1 can be considered as a special case of security mode 2 where o service has registered any security requirements.

#### Security mode 3 (link level enforced security)

When a PAC device is in security mode 3, it shall initiate security procedures before the channel is established.

### Security parameters

PAC security layer uses security parameters. Some example security parameters are as follows.

|  |  |
| --- | --- |
| Parameters | Description |
| PAC\_ADDR | PAC device address (unique for each device) |
| AUTH\_KEY | Authentication key used for authentication purposes |
| ENC\_KEY | Encryption key for secure unicast |
| GENC\_KEY | Group encryption key for secure group communication |
| RAND | Frequently changing random or pseudo-random number |

### Key Derivation

For secure communications between PAC devices in networks, several key materials are derived using the shared secret information between the devices.

Each key material shall be derived selectively on the basis of the security mode.

### Authentication

Authentication is the process of verifying ‘who’ is at the other end of the link. In PAC security layer, authentication is performed for devices, or services.

#### Infrastructureless authentication

PAC networks are fully distributed, and no coordinator is expected to exist to serve as an AAA (Authentication, Authorization, and Accountability) server. Authentication between PDs may be done using secret information shared between devices, or certificates issued by a trusted authority.

Some applications might require only one-way authentication. Some applications might require mutual authentication.

#### Infrastructure authentication

In PAC networks where there is an AAA(Authentication, authorization, accountability) server and a dynamic coordinator, which is a PAC device with intermittent connection to the AAA server, authentication between PAC devices may be achieved using symmetric master key, or certificate issued by the AAA server.

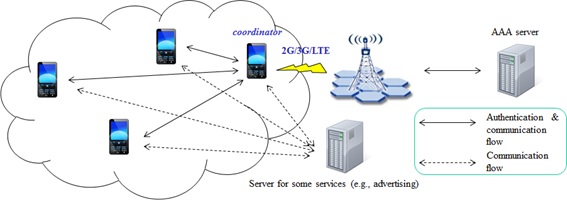


Figure 24. Infrastructure architecture

#### Authorization

Authorization is the process of deciding if device X is allowed to have access to service Y.

Authorization always includes authentication, and grants access rights to devices on the basis of their trust levels.

|  |  |
| --- | --- |
| Device trust level | Description |
| Trusted device | - The device has been previously authenticated  - An authentication key is stored  - The device is marked as “trusted” in the device DB |
| Untrusted device | - The device has been previously authenticated  - An authentication key is stored  - But, the device is not marked as “trusted” in the device DB |
| Unknown device | - No security information is available for this device  - This is also an untrusted device |

Trusted devices (authenticated) are allowed to services, but untrusted or unknown devices may require authorization based on interaction before access to services is granted.

Technically, key would be derived or given (established) to the authorized user during the authorization procedure.

## Coexistence

*Editor: The text below enclosed by <395r1> needs to be improved and enhanced.*

*Volunteers? Jinyoung?*

**<395r1 name=”Jinyoung Chun, LG, jiny.chunWlge.com >**

PAC shall coexistence systems such as IEEE802 using unlicensed bands in section 7.1.1.

**</395r1>**

## Higher layer interaction

***Qing****, can you provide a neural high level text to replace the text below?*

# Physical layer

## Block Diagram

*Editor: The block diagram below illustrates a transmitter with MIMO. However, TG8 has not reached any agreement on whether MIMO will be supported, optional, or mandatory, and thus the following diagram needs to be changed to make it more general. Also, the general block diagram should not mention any specific transmission mode (e.g., OFDM, DFT-S OFDM). Please comment.*



1. —Schematic diagram of common mode PHY

Note: Diagram is so specific. Modify it more generally. Describe each block. Remove Buffer. MIMO will be discussed. Add schematic diagram for Sub 1GHz band and UWB band.

## Channelization

Frequency bands of operation for PAC are sub-GHz band, 2.4 GHz unlicensed band, and 5 GHz unlicensed bands, and UWB band under 11 GHz.

A channelization scheme divides frequency bands into channels, where each channel is characterized by its center frequency and bandwidth.

### Channelization for sub-GHz band, 2.4 GHz and 5 GHz unlicensed bands

Parameters of a channelization scheme include the center frequency of each channel, the number of channels, and the maximum allowed transmit power. Factors that should be taken into account in determining the channelization scheme for PAC include performance, implementation complexity, and coexistence with other systems.

### Channelization for UWB band

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Band plan** | | | | | |
| **Channel index** | **Lower band edge (MHz)** | **Upper band edge (MHz)** | **Region** | **Comment** | **Available mandatory frequencies** |
| 1 | 4200 | 4800 | China | Low band in China | a |
| 2 | 3100 | 4800 | Europe, Korea | Low band in Europe and Korea | a,b,c |
| 3 | 3400 | 4800 | Japan | Low band in Japan | a,b,c |
| 4 | 3100 | 5700 | USA | Low band in USA | a,b,c |
| 5 | 6000 | 9000 | Europe, China | High band in Europe and China | d,e,f,g |
| 6 | 7250 | 10250 | Japan | High band in Japan | e,f,g,h |
| 7 | 7200 | 10200 | Korea | High band in Korea | e,f,g,h |
| 8 | 6000 | 10600 | USA | High band in USA | d,e,f,g,h |
| 9 | 5925 | 7200 | USA | Wideband in USA | d |

|  |  |
| --- | --- |
| **Mandatory frequency\* allocation** | |
| **Index** | **Mandatory frequency (MHz)** |
| a | 3500 |
| b | 4000 |
| c | 4500 |
| d | 6500 |
| e | 7500 |
| f | 8000 |
| g | 8500 |
| h | 9000 |

\* Mandatory frequency is frequency at which PSD level is less than 6 dB below maximum.











## Duplex schemes

PAC uses TDD as a duplex scheme.

## Multiplex schemes

Multiplexing schemes under consideration for PAC are time-division multiplexing, and time-frequency-division multiplexing.

The multiplexing scheme for PAC is OFDM. However, any variants of OFDM are also under consideration if they are proved to have clear advantage over the conventional OFDM. The advantage of a certain multiplexing scheme over another may be measured in terms of performance, complexity, power consumption, etc.

For frequency bands with unique characteristics or applications, multiplexing scheme other than OFDM or its variant can be considered. For example, UWB band under 11 GHz or frequency band under 1 GHz may use different multiplexing schemes to satisfy the unique requirements in the frequency bands.

## PPDU structure

In general, PPDU consists of preamble, physical header, and PSDU, as illustrated in Figure X.



**Figure X**: General structure of typical PPDU.

Preamble is used to perform AGC, packet detection, timing- and frequency- synchronization, and channel estimation. The desired characteristics of a preamble are as follows:

* Good timing synchronization performance
* Good frequency synchronization performance
* Robustness to frequency offset between the transmitter and deceiver
* Good channel estimation performance
* Good mobility support
* Low implementation complexity

The preamble used in PAC shall have a well-balanced combination of the characteristics listed above.

Physical header field contains information required to decode the PSDU. PSDU is equivalent to MPDU, which consists of MAC header, payload, and FCS.

Figure X is a general structure of PPDU. The structure of a PPDU is determined depending on its type, and may be different from the structure illustrated in Figure X. For example, some PPDU types may not have all the fields illustrated in Figure X, while other PPDU types may have additional fields not illustrated in Figures X to support specific functionality of PAC.



































## Modulation and coding scheme (MCS)

*Note: NICT’s proposal is so detail for PFD. Members will discuss depth of text for PFD.*

### Modulation

Modulation schemes under consideration for PAC include BPSK, QPSK, 16QAM, 64QAM, GFSK, , Filtered FSK, OOK, and 2PPM BPSK.

#### Sub 1 GHz band

Modulation schemes under consideration for the sub-GHz band are GFSK, OFDM, and Filtered FSK.

#### 2.4 GHz and 5 GHz band

Modulation schemes under consideration for 2.4 GHz and 5 GHz unlicensed bands are BPSK, QPSK, 16QAM, 64QAM.

#### UWB band

Modulation schemes under consideration for UWB band are OOK, and 2PPM BPSK.















### Coding Scheme

PAC shall use channel coding to protect messages against channel noise or interference from other devices.















## Multiple antennas

PAC supports multiple antenna technologies such as MIMO or beamforming to improve performance or provide specific functionalities. For example, MIMO technologies can be used to increase data rate or reduce packet error rate. Beamforming can be used to increase the SNR of the received signal, extend the coverage, or to aid discovery procedure by providing directivity of discovery signals. PAC may also support other array processing technologies to estimate the angle of arrival of incident signals to provide location base services.

## Bit interleaver

In general, wireless channels are not memoryless, and thus bit errors usually occur in bursts rather than independently. Interference from other systems is another source of bit errors in bursts. However, modern channel coding schemes usually assume the bit errors are distributed independently. PAC supports bit interleaving to improve the performance of forward error correcting code.

## Scrambling

PAC shall have a scrambler, or a randomizer, which is used to shape the data spectrum and to reduce interference.







# UWB Physical (PHY) layer

PAC shares the physical layer specification of IEEE 802.15.4a-2007 with OOK as an additional modulation scheme.







































## Appendix A