**IEEE P802.15**

**Wireless Personal Area Networks**

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| Re: |  | |
| Abstract | This is the clean 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.

**Multicast group ID**: the logical identifier of a multicast group

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

# Abbreviations and acronyms

|  |  |
| --- | --- |
| AAA | Authentication, Authorization, Accountability |
| AGC | Automatic Gain Control |
| BPM | Burst Position Modulation |
| BPSK | Binary Phase-Shift Keying |
| CAP | Contention Access Period |
| CCA | Clear Channel Assessment |
| CFP | Contention Free Period |
| CP | Cyclic Prefix |
| CRC | Cyclic Redundancy Check |
| CS | Channel Sampling |
| CTS | Clear To Send |
| CW | Contention Window |
| FCS | Frame Check Sequence |
| FEC | Forward Error Correction |
| GI | Guard Interval |
| IS | Interference Sensing |
| LFSR | Linear Feedback Shift Register |
| LSB | Least Significant Bit |
| LTF | Long Training Field |
| MAC | Medium Access Control |
| MLME | MAC sublayer Management Entity |
| MLSDE | MAC sublayer Service Discovery Entity |
| MSB | Most Significant Bit |
| OFDM | Orthogonal Frequency Division Multiplexing |
| PAN | Personal Area Network |
| PD | PAC Device |
| PDU | Protocol Data Unit |
| Peering-REQ | Peering-Request |
| Peering-RSP | Peering-Response |
| PHR | PHY Header |
| PHY | Physical layer |
| PID | Peering Identifier |
| PLME | PHY Layer Management Entity |
| PPDU | PHY Protocol Data Unit |
| PRBS | Pseudo-Random Binary Sequence |
| PSD | Power Spectral Density |
| PSDU | PHY Service Data Unit |
| RF | Radio Frequency |
| RTS | Request To Send |
| SC | Single Carrier |
| SDU | Service Date Unit |
| SHR | Synchronization Header |
| STF | Short Training Field |
| SYNC | Synchronization |
| ULA | Uniform Linear Array |
| UWB | Ultra Wide Band |
| ZC | Zadoff-Chu |

# 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.

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Figure . Overall PAC Architecture

A PAC system may contain the following functions at MAC and/or PHY. The block diagram is provided as 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 2. 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 3. 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

## Overview

This clause 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 4.



Figure 4. 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 5 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 5 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 5. 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 6. 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 7. 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 8. 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 multicast group ID(s). To support multicast, the following features are supported:

* Multicast group creation: A PD creates a multicast group.
* Joining multicast group: A PD joins a multicast group.
* Leaving multicast group: A PD leaves a multicast group.

### Broadcast

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

## MPDU structure

MPDU for data communication has a MPDU header and may have a variable length MPDU payload and a fixed length FCS. The MPDU payload is data information. FCS contains CRC check sequence for error detection.



Figure . PAC MPDU format

## Multiple access

Multiple access schemes allow multiple PDs to share a communication medium. Contention-based access as well as contention-free access schemes are considered.

In a contention-based multiple access scheme, multiple PDs compete for channel access.

Contention-free multiple access schemes try to guarantee channel access to PDs so that the PDs do not have to compete for channel access.

## Synchronization procedure

Key desired features of synchronization procedure are as follows:

* The purpose of synchronization is to find, at least, the time boundary either at the PHY or the MAC. The time boundary may be symbol, slot, frame, application frame, super frame, etc.
* Synchronization reference signal may be a sequence or a beacon.
* 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 support low duty cycling for discovery and peering, i.e. low overhead for discovery and peering.
* Synchronization mechanism should efficiently support PDs participating in one or multiple group communications.
* Synchronization mechanism should efficiently support multi-hop communications.

## 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 contains at least peer discovery information.
* A PD may transmit peer discovery message periodically during peer discovery broadcasting.

## QoS

The MAC sublayer may provide differentiated operations according to traffic types.

## Interference management

Interference among multiple links is managed by the threshold level.

## Transmit power control

A PD may perform transmit power control based on channel measurement status.

## Multi-hop operation

To extend the coverage of a PD or group members, a PD or group members relay received data to the destination PD or group members.

## Relative positioning

A PD may measure the relative position of other PDs.

## Power management

A PD should support power management operation including low duty cycling, sleep mode, etc.

## Security

Security functions may provide PDs with privacy, authentication and authorization.

Multi-hop operation should not violate the security provision of PDs.

### Security modes

Security function provides different security modes on the basis of security requirements.

### Authentication

Authentication is the process of verifying peers and services.

#### Infrastructureless authentication

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

One-way or mutual authentications may be supported.

#### Infrastructure authentication

When AAA server and a dynamic coordinator exist, a PD with intermittent connection to the AAA server, authentication between PDs may be achieved using symmetric master key, or certificate issued by the AAA server.

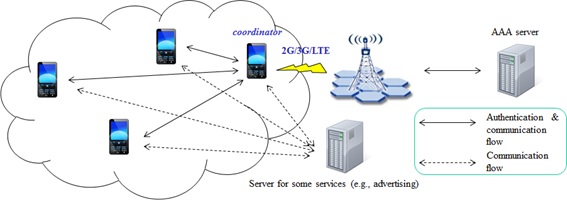


Figure . Infrastructure architecture

#### Authorization

Authorization is the process of deciding if a PD is allowed to access to a certain service provided by a peer.

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

## Coexistence

PAC shall coexist with non-PAC devices operating in unlicensed bands.

## Upper layer interaction

A PD has at least an interface between the MAC and an upper layer.

# Physical layer

## 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.

.

### 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.

## Multiplexing schemes

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

## PPDU structure

In general, PPDU have synchronization header and may have physical header, and PSDU, as illustrated in Figure 11.



Figure . General structure of typical PPDU

Synchronization header is used to perform AGC, PPDU detection, timing- and frequency- synchronization, and channel estimation, etc.

Synchronization header has preamble and may have SFD (Start of Frame Delimiter).

Physical header field contains information required to decode the PSDU.

Other PPDU types may have additional fields not illustrated in Figure 11.

## Modulation and coding scheme (MCS)

### Modulation

Modulation schemes under consideration for PAC include BPSK, QPSK, 16QAM, 64QAM, GFSK, Filtered FSK, Multi-carrier modulation, OOK, and BPM/BPSK.

#### Sub 1 GHz band

Modulation schemes under consideration for the sub-GHz band are GFSK, Multi-carrier modulation, 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 BPM/BPSK.

### Coding Scheme

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

LDPC, convolution code and RS code are under consideration as a coding scheme.

## Multiple antennas

PAC may support 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 based services.

## Bit interleaver

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 interferences.

## UWB Physical (PHY) layer

PAC may support reuse of parts of the UWB physical layer specification of IEEE 802.15.4a-2007.

PAC may also support OOK modulation scheme for UWB PHY.