**IEEE P802.15**

**Wireless Personal Area Networks**

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| Source | Xiaohui Peng, Li Sun, Bin Qian, Kuan Wu, David Xun Yang, Lei Huang, Peng Liu, Ziyang Guo, Chenchen Liu, Wei Lin, Jia Jia, Edward Au, Stephen McCann (Huawei), Pooria Pakrooh, Bin Tian, Steve Shellhammer, Koorosh Akhavan (Qualcomm), Claudio da Silva, Chunyu Hu (Meta), Segev Jonathan (Intel), Weidong Tang, Libra Xiao (New Radio Technology), Jean-Marie André (ST), Sven Zeisberg (Zigpos), Boris Banev, David Barras (3db), Dag Wisland, Kristian Granhaug, Håkon Hjortland, Nikolaj Andersen, Jan Roar Pleym, Dries Neirynck (Novelda AS), Frank Leong, Wolfgang Kuchler, Riku Pirhonen (NXP) |
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| Abstract |  |
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1. UWB sensing

## Introduction

As one of the key functionalities provided by UWB, sensing can enable various applications such as presence detection and environmental mapping. The 15.4ab PAR objective specifically associated with sensing is “*Sensing capabilities to support presence detection and environment mapping*”.

In this document, we would like to provide a framework for UWB sensing in 802.15.4ab that will be developed into a draft. First, we define sensing terminology and operational sensing modes. Based on that, we highlight, sensing procedures, sensing measurement report, coexistence of sensing, ranging and communication, as well as privacy considerations. PHY related changes for sensing will also be discussed. This document will evolve over time. All contributions and suggestions are welcome.

## Terminology

In this section the terminology for UWB sensing can be developed and agreed upon.

*Sensing Initiator:* The sensing device that initiates the RF sensing session with one or more other UWB devices.

*Sensing Responder:* The sensing device that responds to the sensing initiator.

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

*Sensing Receiver:* The sensing device that receives the channel sounding PPDU from the transmitter and performs channel estimation.

*Sensing Requesting Device:* In a proxy application, refers to the sensing device that requests the sensing CIR (channel impulse response) measurement report.

*SDEV*: Sensing Capable Device. A conditionally mandatory basic feature set enabling high-performance UWB sensing.

## Operational modes for UWB sensing

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

### Basic sensing mode

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

* Mono-Static Sensing
* Bi-Static Sensing [Initiator=sensing receiver]
* Bi-Static Sensing [Initiator=sensing transmitter]
* Multi-Static Sensing [Initiator=sensing receiver]
* Multi-Static Sensing [Initiator=sensing transmitter], supporting scheduling of OTA CIR measurement reports from multiple responders.
* Proxy, including basic proxy mode and hierarchical proxy mode.

### Collaborative sensing mode

Support for collaborative sensing where mono-static and multi-static sensing nodes can exchange sensing results. This can enable applications such as collaborative localization or authentication of a person in an environment with distributed sensing devices.

### Simultaneous sensing and ranging mode

In ranging applications, the location of a UWB device is identified by searching for the timestamp corresponding to the shortest path in the CIR, while in sensing applications, CIR can also be utilized to extract the target’s information including range, velocity and angle. Since the information of both the shortest path and the reflected paths are included in the CIR, it is possible to conduct ranging and sensing simultaneously based on the CIR. A revised procedure and related Information Element(s) (IEs) for the existing ranging protocol needs to be provided to support simultaneous ranging and sensing. Optionally, for non-sensing oriented applications, switching pulse shapes for different applications, such as whether to trigger the use of a unified pulse shape for simultaneous sensing and ranging mode defined in 1.8.1.

## Sensing Procedure

The sensing procedure should define sensing frame exchange sequences. There will be frame exchange sequence for each of the Sensing Modes listed in Section 1.3. The existing ranging sequence defined in 802.15.4z can be generalized to define sensing blocks, rounds, and slots. Using this structure, different sensing phases can be specified in a sensing block, including a sensing session setup phase, sensing measurement phase and measurement report phase.

Packet transmission sequences are under consideration to facilitate frequency stitching across carrier frequencies spaced apart in multiples of 124.8MHz.

### Sensing capability exchange

During a sensing session setup, the sensing procedure should define a capability exchange phase for bi-static, multi-static, and proxy scenarios. The list of parameters under negotiation can include device roles, measurement result formats, specific measurements and calculated features to be included in the measurement report. At least one dedicated IE format for sensing will be added.

## Sensing measurement report

Two types of sensing measurement reports will be specified in the standard. The MLME sensing measurement report is used to transmit the sensing measurement results to the application layer of the initiator device. It is sent from the MAC layer to the upper layers within a device over the MAC Layer Management Entity (MLME). Depending on the role of the sensing devices, an OTA sensing measurement report may also be required to transmit the sensing measurement results from a responder to the initiator.

Both an MLME sensing measurement report and OTA sensing measurement report carry the sensing measurement results. Three types of sensing measurement result formats will be considered:

* Window-based CIR Measurement Report which carries the CIR in a specified window. This type is used for most bi-static and multi-static sensing applications.
* Compressed CIR Measurement Report which carries the compressed CIR. This type is used for bi-static, multi-static and proxy sensing applications.
* Processed Target Report which carries the processed channel information such as range, velocity and AoA, etc. for interested target(s). The processed target report is often used for mono-static, bi-static or multi-static sensing with external time and frequency synchronization.

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

### Window-based CIR Measurement report

The CIR is estimated from the received sensing PPDU packets. In this case, a window-based approach for the CIR sensing report is used to provide consistency for multiple CIR measurement reports across packets.

 

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

* The first part contains sensing control parameters, for example fields such as the number of antennas, CIR window duration ($W\_{length}$), CIR window offset ($W\_{offset}$), and phase and latency calibration results for each RF chain. The sensing control parameters may or may not be present in the CIR Measurement Report depending on when the initiator needs them.
* The second part contains content fields for the CIR measurement report, for example, CIR in-phase and quadrature values for each chain, normalization factor for each chain, etc. The window has a reference which can be specified as the earliest detected tap or the strongest detected tap of the CIR (needs to be discussed and determined in the future). The CIR sampling rate for the CIR measurement report needs to be determined.

For the sensing modes where the sensing initiator is the sensing transmitter, the CIR report may be sent OTA, and would be forwarded to the initiator’s upper layer for further processing.

### Compressed CIR Measurement Report

For some sensing modes mentioned in Section 1.3, an OTA sensing measurement report may be sent to transmit the sensing measurement results. To decrease the feedback overhead of multiple CIR measurement reports, and to reduce the air-time, CIR compression may be needed prior to transmission. CIR compression needs to balance the quantization accuracy and signaling overhead, while addressing the large dynamic range issue in CIR measurements.

### Processed target feature report

For mono-static sensing where inherent synchronization is available, and for bi-static and multi-static sensing where external synchronization is utilized, a Processed Target Feature Report will be specified. The Processed Target Feature Report has two parts. The first part contains sensing control parameters, which has fields such as the number of targets in the sensing task, and number of antennas. The second part includes content fields which has sensing features such as range and velocity of the targets, and Angle of Arrival (AoA) of the targets.

For each processed metric of the content fields, the specification will provide its definition and maybe an example of the computation method.

## Privacy considerations in sensing

Privacy issues may be taken into account when designing sensing protocols. Potential solutions need to be investigated, such as:

* Cryptographic approaches: Encryption of the CIR report.
* Physical layer security approaches

## Facilitating the coexistence of sensing, ranging, and communications applications

To promote the wide and successful adoption of 802.15.4 solutions, PHY and MAC features and definitions that facilitate the coexistence of sensing, ranging, and communications applications will be considered.

## Sensing Related PHY Changes

### RF requirements: Sensing Pulse Shape

In sensing applications, the pulse shape should be designed such that the parameters of the reflected paths can be accurately measured. Specific topics that are worthy of investigation include the following:

* Criteria of evaluating the goodness of a sensing pulse shape: In addition to the widely-adopted criteria such as time-domain mask and PSD mask, other metrics such as range resolution, PSLR (peak to sidelobe ratio), spectrum efficiency (or root mean square bandwidth) and zero-Doppler ambiguity function should be introduced to evaluate the performance of a sensing pulse shape.
* A sensing pulse shape should be designed to avoid both pre-ringing and post-ringing.
* A more restrictive time-domain mask should be specified for the sensing pulse shape than ranging.
* The pulse shape should be designed to support both sensing and ranging.

### Sensing packet structures

Support for sensing via additional packet structure configurations is under consideration to take into account the various existing combinations used with an additional sensing field, as well as sensing only options. The sensing functionality may be combined with communication and ranging. The potential combined packet structure should be qualified with the complexity and performance of each functionality.

Both the pulse pattern and sequence need to be investigated for the sensing, e.g., the pulse pattern can be different for mono-static, bi-static/multi-static radar. Maybe bi-static/multi-static can reuse the pulse pattern of ranging. For mono-static sensing, the pulse burst sensing scheme can be a candidate.

The sequence used for sensing can be investigated together with non-secure ranging and the preamble.

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