**IEEE P802.15**

**Wireless Personal Area Networks**

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| Source | Benjamin RolfeBlind Creek AssociatesLos Gatos, CA | Voice: +1 408 395 7207Fax: DeprecatedE-mail: [ben.rolfe @ ieee.org] |
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| Abstract | IEEE 802.15.4 Coexistence Document |
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Contributors of the CA document are sorted by alphabetical order of the last name:

TBD

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# Introduction

This document provides a summary of coexistence analysis which has been performed evaluate the performance of systems using the 802.15.4-2015 HRP and LRP PHYs as amended by P802.15.4z with respect to other 802 wireless standards which may operate in the same band.

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## Acronyms

The acronyms used in this document are taken from [1], [2] and [4]. Definitions of the terms can be found in the same documents.

## Terminology

The following terms, when used in this document, have the following meaning:

“base standard” means 802.15.4-2015 and all approved amendments at the time this document has been prepared.

“802.15.4” means the base standard./

“This amendment” means amendment P802.15.4z: Standard for Low-Rate Wireless Networks Amendment: Enhanced High Rate Pulse (HRP) and Low Rate Pulse (LRP) Ultra Wide-Band (UWB) Physical Layers (PHYs) and Associated Ranging Techniques.

# Overview

802.15.4 UWB based systems widely used world-wide. The initial release of 802.15.4a-2007 introduced the HRP UWB PHY to the standard, and the LRP UWB PHY was added by 802.15.4f-2010. Amendment P802.5.4z extends both UWB PHYs to address new and existing applications. Current UWB systems operate all over the world, at very low power spectral density. This document provides analysis of coexistence with other 802 wireless systems, including legacy 802.15.4 systems and existing 802.11 systems.

There are multiple existing sources of information on UWB coexistence available. The method used in this document is to summarize the findings with respect to coexistence between 802 wireless systems which may operate in the same bands. The referenced CADs for 802.15.4a [8] and 802.15.4f [9] and coexistence studies [10][11] characterize coexistence performance between UWB PHYs with the following systems:

* 802.15.4 PHYs operating in the overlapping bands
* 802.16 operating in the 3.4 to 3.8 GHz band
* 802.11 OFDM operating in 5GHz and 6GHz bands

In general worldwide, UWB systems operate at very low transmit power, typically limited to power spectral density (PSD) limits aligned with the spurious and/or unintentional electromagnetic emissions limits established for unintentional radiators. For example in the US, as well as many parts of Asia and in Europe the PSD limit is -41.3 dBm.

## Overview of 802.15.4z UWB

### Frequency bands of interest

Figure 1 depicts the 802.15.4 UWB channel plans defined in the base standard and as extended by this amendment. Amendment 802.15.4z defines new ranging capable devices with extended capabilities that operate in the high band channel plan; no changes to devices operating in the low band channel plans are included in this amendment.



Figure 1: Spectrum Graphic

The LRP channel plan is extended by this amendment as shown with the addition of channel definitions in the UWB High band. The HRP channel plan is not changed by this amendment. The “Globally available UWB spectrum” highlighted illustrates the channels in the UWB channel plan that is available in all the regulatory domains that provide for operation LRP and HRP devices as defined in the base standard and this amendment. Other channels are available in a more limited set of regulatory domains.

### Relevant 802 Standards

Table 1 lists the other 802 standard that may operate in overlapping bands.

Table 1: Other 802 Wireless Standards in the Subject Bands

|  |  |  |  |
| --- | --- | --- | --- |
| Standard | Frequency Range (MHz) | PHY description | Reference Clause |
| 802.15.4 | 3244–4742  | HRP UWB low band | 16 |
| 802.15.4 | 5944–10 234 | HRP UWB high band | 16 |
| 802.15.4 | 6289.6–9185.6 | LRP UWB | 19 |
| 802.15.4 | 4940–4990  | LMR DSSS DPSKLMR DSSS BPSK | 28 |
| 802.15.4 | 5725–5850  | LMR DSSS DPSKLMR DSSS BPSK | 29 |
| 802.11-2016 | 4000 -  | 10, 20, 40 MHz channel spacing |  |
| 802.11-2016 | 4002.5 | 5 |  |
| 802.11-2016 | 4850 | 20 |  |
| 802.11-2016 | 4890 - | 10,20, 80, 160 MHz channel spacing |  |
| 802.11-2016 | 4937.5 - | 5 MHz channel spacing |  |
| 802.11-2016 | 5000 -  | 10, 20, 40, MHz channel spacing |  |
| 802.11-2016 | 5002.5  | 5 |  |
| 802.11ax-D04 | 5940 | 10,20, 80, 160 |  |
| 802.16-2012 | 3400 - 3800  |  |  |
|  |  |  |  |

Note that the majority of WLAN applications use channel spacing 20 to 80 MHz.

### LRP PHY

This amendment extends the LRP PHY to support additional

* New PHY packet formats
	+ Frame duration likely to be shorter– less impact and smaller exposure
		- Fewer pulses and shorter packet duration.
		- More robust in presence of interference
		- PSD and peak same as legacy UWB
		- Energy levels haven’t changed
		- More likely to have duration in time and less energy per packet
* New modulation and PRF
	+ Net no change in impact
	+ May be more robust to interference

### HRP

Reference to standard

* New modulation and PRFs
	+ Doesn’t use BPM
	+ Peak PRF hasn’t changed
	+ Mean PRF may change but averages to the same energy (reg limits)
	+ New codes – take advantage of higher mean PRF enable higher data rate,, less frame overhead, may result in reduced duration frame transmission
	+ Higher data rates added lower overhead etc good both ways
* Adding additional preamble codes – enables more spectral reuse, etc.
* Impacts on legacy HRP:
	+ new codes ignored by legacy devices without harm;
	+ Compatible PHY modes to interoperate with legacy devices;
* More reliable transmission
	+ Instantaneous peak power better controlled
	+ Reduce retransmissions required

### MAC Enhancements and Coexistence Impact

The new MAC features added by this amendment use the exiting features of the MAC to assure compatibility with legacy 802.15.4 devices as well as preserve the proven coexistence characteristics provided by the standard. The MAC is extended by this amendment with provisions used by Ranging PHYs as follows:

* Broadcast / multicast options: Provision for scheduled broadcast and multicast exchanges
* New information elements to convey information used for ranging related information exchange
* MAC features to control ranging exchanges with enhanced integrity verification
* MAC SAP changes to support new ranging control and exchange

The channel access methods used to assess channel condition and commence transmission are not altered by these additional MAC features. The impact on coexistence is minimal.

## Overview of Coexistence Mechanisms in 802.15.4

Coexistence mechanisms in 802.15.4 are described in [8] and [9]. Coexistence is also enhanced by the inherently low duty cycle nature of 802.15.4 due to the MAC architecture, as explained in [13].

The MAC changes introduced in this amendment will have minimal impact coexistence performance:

* New scheduling options are equivalent to and compatible with existing channel access mechanisms (CSMA-CA)
* The new features preserve the coexistence mitigations with respect to loading, effective duty cycle, and channel access as described in [8]. Several features reduce over the air overhead, which will decrease interference footprint both as victim and assailant.

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## Coexistence Analysis Methodology

The Coexistence studies referenced in this document generally follows the methodology as described in [12] examining the impacts of each subject system as both assailant and victim. For this document, the existing coexistence analysis was examined for relevance to the current 802 standards and we summarize the results which are relevant. 802 wireless standards are not static, and there have been and so additional studies have been performed and made available, specifically evaluating coexistence between 802.15.4 UWB and 802.11 systems. Conclusions drawn from the results of these studies are provided in this document.

The coexistence studies sited in this document use a Monte Carlo simulation method to assess potential impacts when sharing spectrum.

# Dissimilar Systems Sharing the Same Frequency Bands

This clause presents coexistence considerations with other 802 systems which are specified to operate in some of the same frequency bands. For the purpose of this clause, dissimilar is defined as other than IR-UWB operating according to the 802.15.4 LRP or HRP PHY specifications.

## 802.11 Coexistence

As detailed in Annex E of [5] and [6], 802.11 systems may operate in a variety of bands as shown in Table 1 at channel spacing from 5 MHz to 160 MHz. 802.11 based WLAN devices may operate at relatively high EIIRP up to 1000mW (30dBm) in some regions. UWB devices operate with a mean EIRP limited to -41.3 dBm/MHz. 802.15.4 UW devices use nominal bandwidth of 500 MHz or higher.

Studies [10] and [11] present simulation results illustrating impacts from 802.11 systems operating in proximity to 802.15.4 UWB based systems. The study considers a variety of deployment scenarios and sets of operating conditions.

### 802.11 WLAN impact on 802.15.4 UWB

Results for the scenarios covered in [10] and [11] illustrate the potential impacts. The WGSE PT45 study [10] examines both single interference and aggregate interference via simulation methods combined with data from measurements of live signals. The results show that 802.11 based WLAN interferers up to 946 meters away cause more than 3 dB sensitivity reduction in UWB communications and location tracking systems. For sensing applications, the equivalent distance is 212 meters. Aggregate interference evaluation with Monte Carlo simulations show that at WLAN duty cycle of 1.97%, the probability that the sensitivity reduction to UWB communications and location tracking devices exceeds 3 dB falls between 5 and 15%. For sensing device, the probability that the sensitivity reduction is more than 3 dB is between 3 and 6%

In [11], additional configurations and scenarios are investigated using simulation techniques. The studies show significant impacts on both communication and ranging/location.

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### 802.15.4 UWB impact on 802.11 WLAN

UWB devices operate with a mean EIRP limited to -41 dBm/MHz, the pathloss required to limit 802.11 de-sense of 3dB by a UWB device is outlined in the table below.

Table 2: Computation of the interference threshold for 802.11 System

|  |  |  |
| --- | --- | --- |
| **Quantity** | **Value** | **Unit** |
| UWB TX PSD Limit | -41 | dBm/MHz |
| Thermal noise floor | -114 | dBm/MHz |
| 802.11 device noise figure | 6 | dB |
| Effective 802.11 device operating noise floor | -108 | dBm/MHz |
| Required UWB -> 802.11 device pathloss | 67 | dB |

With a worst case free space pathloss model given in the equation below, where *Pl(d*0*)* is the pathloss at the reference distance of *d*0 = 1m.

In the 6GHz band, the *Pl(d*0*)* is 48dB, based on the Friis equation,

Using this model, the required separation to achieve 67 dB of pathloss is under 9m. Note that this is a worst-case scenario, since shadowing and non-line-of-sight effects are not considered; these will reduce the required separation even further.

For illustration purposes, the following Table shows the path losses at the reference distance *d*0 along with the minimum required separation distances for example frequencies from 3 GHz to 6 GHz:

Table Path losses reference

|  |  |  |
| --- | --- | --- |
| **Carrier Frequency** | **Loss at Reference Distance of 1m** (rounded to nearest integer) | **Required separation distance to achieve 67 dB of total path loss** (rounded to nearest higher integer) |
| 3 GHz | 42 dB | 18 m |
| 4 GHz | 44 dB | 14 m |
| 5 GHz | 46 dB | 11 m |
| 6 GHz | 48 dB | 9 m |

## 802.15.4 Coexisting Systems

The RCC PHYs may operate in the bands as shown in Table 1. It is not expected that RCC PHYs would be operated in proximity to UWB PHYs. RCC is used primarily outdoors and in proximity to rail lines.

## Other 802 Wireless systems considered

Reference [8] details coexistence properties between 802.15.4 UWB and 802.16 based systems. The results indicates that the PER drops below 1% at a separation distance of 1m and at separaration distances > 6.9 meters the impact on the 802.16 from the LRP UW signal becomes negligible.

The results indicate that with the 802.16 system as interferer and the HRP UWB system as victim, the per drops below 1% at a separation distance of 44m and at separation distance over 140m becomes negligible.

The signal structure, bandwidth and power spectral density of the LRP symbol is sufficiently similar to the HRP signal that the results for LRP are expected to be similar to what is shown in Reference [8].

#  802.15.4 UWB systems

Legacy HRP and LRP

## HRP

The legacy 802.15.4a HRP and the new 802.15.4z HRP modes both use preamble sequences for synchronization and ranging purposes. For both standards the sequences are designed to be robust to interference. The sequences in either standard will have very low correlation with the sequence of the other. Inter-standard interference between preambles will be virtually identical to intra-standard interference.

Both standards use a bandwidth of 500 MHz. Both use a symbol duration of 128 ns for operation at ~7Mbit/s and a symbol duration of 32 ns at ~30 Mbit/s. 802.15.4z HRP uses higher PRFs than 802.15.4z HRP. The transmit power back off may be slightly different because of peak transmit spectrum constraints. Nonetheless inter-standard interference will be essentially the same as intra-standard interference.

## LRP

# Summary conclusions

# Interference Avoidance and Mitigation Techniques

# Conclusions

As a victim, 802.15.4p FSK has comparable BER performance with the other 802 FSK systems; 802.15.4p DSSS has much better BER performance than the other 802 DSSS systems due to option of the high spreading factor values.

As an interferer, either 802.15.4p FSK or 802.15.4p DSSS has similar performance impact to the other 802 systems at the same transmitting power level. However the performance degradation to the other systems can become significant as the transmitting power is increased up to the possible maximum 30dBm. This requires more physical distance from other 802 systems if an 802.15.4p system is designed to operate at a high transmitting power level.