**IEEE P802.15**

**Wireless Personal Area Networks**

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# 1 Introduction

## 1.1 Bibliography

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(B2) IEEE Std. 802.15.2 – 2003, IEEE Recommended Practice for Information Technology – Telecommunications and Information exchange between systems – Local and metropolitan area networks – Specific requirements – Part 15.2: Coexistence of Wireless Personal Area Networks with Other Wireless Devices Operating in Unlicensed Frequency Bands.

(B3) IEEE Std. 802.15.3 – 2003, IEEE Standard for Information Technology – Telecommunications and Information exchange between systems – Local and metropolitan area networks – Specific requirements – Part 15.3: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for High Rate Wireless Personal Area Networks (WPANs).

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(B5) IEEE Std. 802.15.4e – 2012, IEEE Standard for Information Technology – Telecommunications and Information exchange between systems – Local and metropolitan area networks – Specific requirements – Part 15.4: Low-Rate Wireless Personal Area Networks (LRWPANs) Amendment to the MAC sub-layer.

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Monitoring Networks

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(B8) IEEE Std. 802.15.4f – 2012, IEEE Standard for Information Technology – Telecommunications and Information exchange between systems – Local and metropolitan area networks – Specific requirements – Part 15.4: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low-Rate Wireless Personal Area Networks (WPANs) – Amendment 2: Active Radio Frequency Identification (RFID) System Physical Layer (PHY)

(B9) IEEE Std. 802.11 – 2011 IEEE Standard for Information Technology – Telecommunications and Information exchange between systems – Local and metropolitan area networks – Specific requirements – Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications.

(B10) IEEE Std. 802.15.4g TG4 Coexistence Assurance Document (IEEE 802.15-10-00668-05-004g)

(B11) IEEE Std. 802.15.4 Coexistence analysis of IEEE Std. 802.15.4 with other IEEE standards and proposed standards (IEEE 802.15.10-0808-00)

(B12) IEEE Std. 802.15.4p TG4p PAR (IEEE 802.15.12-0nnn-nn-0SGp)

# 2 Overview

The overview of 802.15.4p is summarized in Section 5.2 Scope of TG4p PAR (Bnn).

## 2.1 Regulatory Information

The available US and European frequency bands for 802.15.4p are given as below:

(a) 160.170 – 161.580 MHz

(b) 216 - 217 MHz

(c) 217 - 220 MHz

(d) 220 - 222 MHz

(e) 450 – 470 MHz

(f) 769 - 775 MHz

(g) 799 - 805 MHz

(h) 806 – 821 / 851 - 866 MHz

(i) 863 – 870 MHz (Europe)

(j) 896 – 901 / 935 – 940 MHz

(k) 901 – 902 MHz

(l) 902 – 928 MHz

(m) 928 - 952 MHz

(n) 2400 – 2483.5 MHz

(o) 4940 – 4990 MHz

(p) 5250 – 5350 MHz

(q) 5470 – 5725 MHz

(r) 5650 – 5925 MHz

(o) 5725 – 5850 MHz

From the above list, bands (e) and (j) – (n) may be occupied by different 802.15.4p PHYs. These are listed in Table 1, below.

Table 1 Frequency Bands for 802.15.4p PHYs

|  |  |  |  |
| --- | --- | --- | --- |
| Frequency Band (MHz) | IEEE 802.15.4p PHYs | | |
| RCC LMR | RCC DSSS BPSK | RCC Ranging |
| 160.170 – 161.580 | X |  |  |
| 216 – 217 | X |  |  |
| 217 – 220 | X |  |  |
| 220 – 222 | X |  |  |
| 450 – 470 | X |  |  |
| 769 – 775 | X |  |  |
| 799 – 805 | X |  |  |
| 806 – 821 / 851 – 866 | X |  |  |
| 863 – 870 | X |  |  |
| 896 – 901 / 935 – 940 | X |  |  |
| 901 – 902 | X |  |  |
| 902 – 928 | X | X | X |
| 928 – 952 | X |  |  |
| 4940 – 4990 | X | X |  |
| 5250 – 5350 | X | X | X |
| 5470 – 5725 | X | X | X |
| 5650 – 5925 | X | X | X |
| 5725 - 5850 | X | X | X |

## 2.2 Overview of Coexistence Mechanisms in 802.15.4 and 802.15.4p

The importance of a coexistence mechanism in 15.4p is manifold. 15.4p specifies three alternative PHYs that shall be able to coexist with each other if operating co-located in the same frequency band. 15.4p also has to share multiple frequency bands and coexist with dissimilar 802 systems.

The coexistence mechanisms specified in 802.15.4 and subsequent amendments are applicable to both homogeneous (among different 15.4p PHYs) and heterogeneous (across other 802 systems) coexistence.

# 3 Dissimilar Systems Sharing the Same Frequency Bands with 802.15.4p

This clause presents an overview on other 802 systems which are specified to operate in some of the same frequency bands that are also specified for 802.15.4p. The following sub-clauses present collocated dissimilar systems with reference to respective frequency bands which are shared by dissimilar 802.15.4 systems.

The frequency bands of interest are the 160.170 – 161.580 MHz band, 216 - 217 MHz band, 217 – 220 MHz band, 220 – 222 MHz band, 450 - 470 MHz band, 769 – 775 MHz band, 799 – 805 MHz band, 806 – 821 / 851 – 866 MHz band (paired), 863 – 870 MHz band, 896 – 901 / 935 – 940 MHz band (paired), 902 – 902 MHz band, 902 – 928 MHz band, 938 – 952 MHz band, 2400 – 2483.5 MHz band, 4940 – 4990 MHz band, 5250 – 5350 MHz band, 5470 – 5725 MHz band, 5650 – 5925 MHz band, and 5725 – 2825 MHz band.

In this and following clauses, each frequency band is discussed referring to a table listing all the coexisting systems from other standard specifications. The contents of the tables are formatted as below:

1. Standard specification: the name of the 802 system with which 802.15.4p system is coexisting.
2. PHY specification: the PHY design of the above 802 system specification
3. Receiver bandwidth: the receiver bandwidth of the above 802 system specification
4. Transmit power: the transmit power of the above 802 system specification
5. Receiver sensitivity: the receiver sensitivity of the above 802 system specification.
6. Involved 802.15.4p system: the particular PHY in 802.15.4p that is coexisting with the above 802 system specification

Note: The data rate modes, including receiver bandwidth, transmit power and receiver sensitivity listed in the columns of the following tables, are only a part of the complete list from the respective standard specifications. These data rate modes are chosen for the purpose of coexistence analysis in this document.

## 3.1 Coexisting Systems in 160.170 – 161.580 MHz Band

No existing 802 systems share the 160.170 - 161.580 MHz band with 802.15.4p PHYs. If there were, the LMR PHY would be capable of crushing any invaders with our superior coding and error correction.

## 3.2 Coexisting Systems in 216 - 217 MHz Band

No existing 802 systems share the 216 – 217 MHz band with 802.15.4p PHYs.

## 3.3 Coexisting Systems in 217 - 220 MHz Band

No existing 802 systems share the 217 – 220 MHz band with 802.15.4p PHYs.

## 3.4 Coexisting Systems in 220 - 222 MHz Band

No existing 802 systems share the 220 – 222 MHz band with 802.15.4p PHYs.

## 3.5 Coexisting Systems in 450 - 470 MHz Band

## At this time, there is one approved standard for operation in this band: IEEE 802.15.4-2012 (specifically the 15.4g amendment). However, in the US this is a licensed band under CFR 47 (US FCC) Part 90 rules, and so any usages shall be controlled by the licensee and the frequency coordinator for that band segment. Therefore, it is highly improbable that the licensee shall choose to put to mutually interfering systems on the same channel.

## 3.6 Coexisting Systems in 769 - 775 MHz Band

No existing 802 systems share the 269 – 775 MHz band with 802.15.4p PHYs.

## 3.7 Coexisting Systems in 799 - 805 MHz Band

No existing 802 systems share the 799 – 805 MHz band with 802.15.4p PHYs.

## 3.8 Coexisting Systems in 806 – 821 / 851 – 866 MHz Band

No existing 802 systems share the 806 – 821 / 851 – 866 MHz band with 802.15.4p PHYs.

## 3.10 Coexisting Systems in 863 – 870 MHz Band

Table 2 shows other 802 systems that share the 863 – 870 MHz band with 802.15.4p PHYs.

Table 2 Dissimilar Systems Coexisting with 802.15.4p within 863 - 870 MHz Band

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Standard | Standard PHY | Involved 802.15.4 PHY | | |
| RCC LMR | RCC DSSS BPSK | RCC Ranging |
| 802.15.4 | BPSK | X | X |  |
| ASK | X | X |  |
| O-QPSK | X | X |  |
| MR-FSK | X | X |  |
| MR-OFDM | X | X |  |
| MR-O-QPSK | X | X |  |

## 3.11 Coexisting Systems in 896 – 901 / 935 – 940 MHz Paired Bands

## At this time, there is one approved standard for operation in this band: IEEE 802.15.4-2012 (specifically the 15.4g amendment). However, in the US this is a licensed band under CFR 47 (US FCC) Part 90 rules, and so any usages shall be controlled by the licensee. Therefore, it is highly improbable that the licensee shall choose to put to mutually interfering systems on the same channel.

## 3.12 Coexisting Systems in 901 – 902 MHz Band

## At this time, there is one approved standard for operation in this band: IEEE 802.15.4-2012 (specifically the 15.4g amendment). However, in the US this is a licensed band under CFR 47 (US FCC) Part 24 rules, and so any usages shall be controlled by the licensee. Therefore, it is highly improbable that the licensee shall choose to put to mutually interfering systems on the same channel.

## 3.13 Coexisting Systems in 902 – 928 MHz Band

Table 2 shows other 802 systems that share the 902 – 928 MHz band with 802.15.4p PHYs.

Table 3 Dissimilar Systems Coexisting with 802.15.4p in the 902 – 928 MHz Band

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Standard | Standard PHY | Involved 802.15.4 PHY | | |
| RCC LMR | RCC DSSS BPSK | RCC Ranging |
| 802.15.4 | BPSK | X | X | X |
| ASK | X | X | X |
| O-QPSK | X | X | X |
| MR-FSK | X | X | X |
| MR-OFDM | X | X | X |
| MR-O-QPSK | X | X | X |

## 3.14 Coexisting Systems in 928 – 952 MHz Band

Table 3 shows other 802 systems that share the 928 - 952 MHz band with 802.15.4p PHYs.

Table 4 Dissimilar Systems coexisting with 802.15.4p within 928 - 952 MHz band

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Standard | Standard PHY | Involved 802.15.4 PHY | | |
| RCC LMR | RCC DSSS BPSK | RCC Ranging |
| 802.15.4 | BPSK | X | X | X |
| ASK | X | X | X |
| O-QPSK | X | X | X |
| MR-FSK | X | X | X |
| MR-OFDM | X | X | X |
| MR-O-QPSK | X | X | X |

## 3.15 Coexisting Systems in 2400 – 2483.5 MHz Band

Table 2 shows other 802 systems that share the 2400 – 2483.5 MHz band with 802.15.4p PHYs.

Table 5 Dissimilar Systems coexisting with 802.15.4p within 2400 - 2483.5 MHz Band

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Standard | Standard PHY | Involved 802.15.4p PHY | | |
| RCC LMR | RCC DSSS BPSK | RCC Ranging |
| 802.15.1 | FHSS GFSK | X | X | X |
| 802.15.3 | SC D-QPSK | X | X | X |
| 802.15.4 | O-QPSK | X | X | X |
| 802.15.4 | CSSS | X | X | X |
| 802.11b | DSSS | X | X | X |
| 802.11g | DSSS | X | X | X |
| 802.11g | OFDM | X | X | X |
| 802.11n | OFDM | X | X | X |

## 3.16 Coexisting Systems in 4940 - 4990 MHz Band

At this time, there is one approved standard for operation in this band: IEEE 802.15.11-2011. However, this band is separated into 1 MHz wide channels that are not comingled with the aggregable 5 MHz channels. The 802.15.4p usage is restricted to the 1 MHz wide channels that are at both band edges. Thus, there is no potential for co-channel interference.

## 3.17 Coexisting Systems in 5250 - 5350 MHz Band

In the 5250 - 5350 MHz band, IEEE 802.11-2011 is the only other 802 system sharing this band with the proposed 802.15.4p PHYs. In the US under 47 CFR 15 UNII band rules, all subject users are required to meet the same TX power output rules. The primary difference between 802.11 and 802.15.4p systems in this band is occupied bandwidth. As the proposed 802.15.4p systems have a significantly narrower bandwidth than most of the 802.11 systems used in this band, the primary impact with co-channel use will be interference to the 802.11 system.

Table 6 Dissimilar Systems coexisting with 802.15.4p within 5250 - 5350 MHz band

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Standard | Standard PHY | Involved 802.15.4p PHY | | |
| RCC LMR | RCC DSSS BPSK | RCC Ranging |
| 802.11a | OFDM | X | X | X |
| 802.11n | OFDM | X | X | X |

## 3.18 Coexisting Systems in 5470 - 5725 MHz Band

shows other 802 systems that share 5470 - 5725 MHz band with 802.15.4p PHYs

Table 7 Dissimilar Systems coexisting with 802.15.4p within 5470 - 5725 MHz band

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Standard | Standard PHY | Involved 802.15.4p PHY | | |
| RCC LMR | RCC DSSS BPSK | RCC Ranging |
| 802.11a | OFDM | X | X | X |
| 802.11n | OFDM | X | X | X |

## 3.19 Coexisting Systems in 5650 - 5925 MHz Band

Table 8 shows other 802 systems that share the 5650 - 5925 MHz band with 802.15.4p PHYs

Table 8 Dissimilar Systems coexisting with 802.15.4p within 5650 - 5925 MHz band

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Standard | Standard PHY | Involved 802.15.4p PHY | | |
| RCC LMR | RCC DSSS BPSK | RCC Ranging |
| 802.11a | OFDM | X | X | X |
| 802.11n | OFDM | X | X | X |

## 3.20 Coexisting Systems in 5725 - 5850 MHz Band

Table 9 shows other 802 systems that share the 5725 - 5850 MHz band with 802.15.4p PHYs

Table 9 Dissimilar Systems coexisting with 802.15.4p within 5725 - 5850 MHz band

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Standard | Standard PHY | Involved 802.15.4p PHY | | |
| RCC LMR | RCC DSSS BPSK | RCC Ranging |
| 802.11a | OFDM | X | X | X |
| 802.11n | OFDM | X | X | X |

# 4 Coexistence Scenario and Analysis

## 4.1 PHY Modes in the 802.15.4p System

### 4.1.1 Parameters of the 802.15.4p PHY Modes

The PHY modes selected from both the FSK and DSS PHYs, along with their corresponding parameters are tabulated in Table 9.

Table 9: Major Parameters of 802.15.4p PHY Modes

### 4.1.2 BER / FER Calculations for 802.15.4p PHY Modes

As defined in TG4g Coexistence Assurance Document section 4.1.2 (B10), the BER and FER are modeled in MatLab with uncoded AWGN channel without interference for 802.15.4p PHY modes. The receiver bandwidth is assumed to be equal to the channel spacing of the PHY mode. The BER and FER plots of the 802.15.4p PHY modes with different spreading factorsin 2.4GHz band are illustrated in Figure 1, Figure 2, Figure 3 and Figure 4. Since different band’s frequency contributes to different path loss which is reflected in the SNR value, the BER and FER vs. SNR performance curves in Figure 1, Figure 2, Figure 3 and Figure 4 are also applicable to the 4k systems in other bands.

1 Tx power 0dBm is used for 4k as victim and 15dBm for 4k as interferer for all the bands except 2.4GHz band, in which 0dBm, 15dBm and 30dBm are used for 4k as interferer for possible scenario comparison.

2 Receiver Sensitivity = Max Tx Power (30dBm) – Typ. Path Loss (120dB).

3 The modulation index, h, for FSK modulation is 1.0 for all frequency bands except the 169.400 – 169.475 MHz band, where the h shall be 0.5

4 For the 470 – 510 MHz and 863 – 870 MHz bands, the chip rate shall be 100 kc/s and channel spacing 200 kHz

In Figure 1, only BPSK with SF = 64 is shown for DSSS and all the other DSSS BERs are based on O-QPSK. By comparing the BPSK and O-QPSK with SF = 64, the BPSK’s performance is around 0.8dB better than the O-QPSK. For the rest of performance analyses, only O-QPSK is used for 4k DSSS.

Figure 1: BER vs. SNR for 802.15.4p FSK and DSSS

Figure 2: BER vs. SNR for 802.15.4p DSSS

Figure 3: FER vs. SNR for 802.15.4p FSK and DSSS

Figure 4: FER vs. SNR for 802.15.4p DSSS

4.2 Interference Modeling

802.15.4g’s interference model, described in section 4.2 of TG4g Coexistence Assurance Document (B10), is adopted for 802.15.4p’s coexistence simulation modeling.

* In the coexistence model, the transmitting power and distance between the victim’s transmitter and receiver are fixed, thusthe received signal strength is fixed. The interference at the victim’s receiver is injected accordingly vs. the distance from the interferer’s transmitter to the victim’s receiver.
* Hata channel model (large scale urban) is used for the interference calculation. No AWGN noise is included in the channel to limit the factors affecting the system’s performance to interference only. Therefore the coexistence performance analysis herein is mainly focused on the interference caused by the interferer’s transmitter.
* There is no frequency offset between the interferer’s center frequency and the victim’s center frequency in the spectrum. This assumes the worst case, that the center frequency of 4k and co-ex PHYs are coincident.
* The victim’s receiver bandwidth is assumed to be the same as the channel spacing, worse than the real implementation.
* Antenna gain is assumed 0dBi.
* For 802.15.4p DSSS PHY, O-QPSK and spreading factor of 64 are used for the worst case.
* Unless specifically mentioned, Tx power 0dBm is used for 802.15.4p as victim and 15dBm for 802.15.4p as interferer.

## 4.3 169.400 – 169.475 MHz Band Coexistence Performance

This sub-clause presents the coexistence performance of the systems coexisting in the 169.400 - 169.475 MHz band. In order to understand the impact of the generated interference, 802.15.4p systems and other coexisting 802 systems in this frequency band MHz band are set as both the victim and interferer source.

### 4.3.1 Parameters for Coexistence Quantification

The following sub-clauses present the parameters involved in quantification of coexistence analysis amongst the participating systems.

#### 4.3.1.1 PHY Mode Parameters of Coexisting Standards

Table 10 shows the PHY mode parameters of coexisting standards within the frequency band

Table 10: Major Parameters of Coexisting 802 Systems in the 169.400 - 169.475 MHz Band

#### 4.3.1.2 BER / FER for PHY Modes of Coexisting 802 Standards

In this sub-clause, the BER / FER performance corresponding to SNR for all the 802 standards within the frequency band are presented. The parameter SNR is defined as the ratio between the energy in each chip to the noise power spectral density in each chip. The average frame size of 20 octets for 802.15.4g MR-FSK FSK 4.8 kb/s and 250 for 802.15.4p FSK are used for FER calculation. The BER and FER curves are illustrated in Figure 5.

Figure 5: BER/FER vs. SNR for 802.15.4g MR-FSK (169.400 - 169.475MHz band)

### 4.3.2 Coexistence Simulation Results

#### 4.3.2.1 802.15.4p PHY Mode as Victim Receiver

Figure 6 shows the BER/FER performance of the 802.15.4p FSK PHY mode victim receiver corresponding to the distance from the 802.15.4g interferer transmitter to the 802.15.4p victim receiver.

Figure 6: Victim BER/FER vs. Distance from Interferer Tx to 802.15.4p FSK Victim Rx

#### 4.3.2.2 802.15.4g PHY Mode as Victim Receiver

Figure 7 shows the BER/FER performances of the 802.15.4g victim receiver corresponding to the distance from the 802.15.4p interferer transmitter to the 802.15.4g victim receiver at different interferer’s transmitting power. Different interferer’s transmitting power levels are simulated for studying the relative performance degradations due to the interferer’s transmitting power. 0dBm and 15dBm are the typical values for device and coordinator’s transmitting power respectively, 30dBm is for the coordinator’s possible maximum power level.

Figure 7: Victim BER/FER vs. Distance from Interferer Tx to 802.15.4g MR-FSK Victim Rx

## 4.4 433.05 – 434.79 MHz Band Coexistence Performance

This sub-clause presents the coexistence performance of the systems coexisting in the 433.05 – 434.79 MHz frequency band. In order to understand the impact of the generated interference, 802.15.4p systems and other coexisting 802 systems in this frequency band MHz band are set as both the victim and interferer source.

### 4.4.1 Parameters for Coexistence Quantification

The following sub-clauses present the parameters involved in quantification of coexistence analysis amongst the participating systems.

#### 4.4.1.1 PHY Mode Parameters of Coexisting Standards

Table 11 shows the PHY mode parameters of coexisting standards within the frequency band

Table 11: Major Parameters of Coexisting 802 Systems in the 433.05 – 433.79 MHz Band

#### 4.4.1.2 BER / FER for PHY Modes of Coexisting 802 Standards

In this sub-clause, the BER / FER performance corresponding to SNR for all the 802 standards within the frequency band are presented. The average frame size of 250 octets is used for both 802.15.4f MSK and 802.15.4p FSK for FER calculation. The BER and FER curves are illustrated in Figure 8.

Figure 8: BER/FER vs. SNR for 802.15.4f(433.05 – 434.79MHz band)

### 4.4.2 Coexistence Simulation Results

#### 4.4.2.1 802.15.4p PHY Mode as Victim Receiver

Figure 9 shows the BER/FER performances of the 802.15.4p FSK PHY mode victim receiver corresponding to the distance from the interferer transmitter to the 802.15.4p victim receiver with the bandwidth of 100kHz and 200kHz.

Figure 9: Victim BER/FER vs. Distance from Interferer Tx to 802.15.4p FSK Victim Rx

#### 4.4.2.2 802.15.4g PHY Modes as Victim Receiver

Figure 10 shows the BER/FER performances of the 802.15.4g victim receiver corresponding to the distance from the 802.15.4p interferer to the 802.15.4g victim receiver. The transmitting power levels of different interferers are simulated for studying the relative performance degradations due to the interferer’s transmitting power. 0dBm and 15dBm are the typical values for device and coordinator’s transmitting power respectively, 30dBm is for the coordinator’s possible maximum power level.

Figure 10: Victim BER/FER vs. Distance from Interferer Tx to 802.15.4f MSK Victim Rx

## 4.5 470 – 510 MHz Band Coexistence Performance

This sub-clause presents the coexistence performance of the systems coexisting in the 470 – 510 MHz frequency band. In order to understand the impact of the generated interference, 802.15.4p systems and other coexisting 802 systems in this frequency band MHz band are set as both the victim and interferer source.

### 4.5.1 Parameters for Coexistence Quantification

The following sub-clauses present the parameters involved in quantification of coexistence analysis amongst the participating systems.

#### 4.5.1.1 PHY Mode Parameters of Coexisting Standards

Table 12 shows the PHY mode parameters of coexisting standards within the frequency band

Table 12: Major Parameters of Coexisting 802 Systems in the 470 – 510 MHz Band

#### 4.5.1.2 BER / FER for PHY Modes of Coexisting 802 Standards

In this sub-clause, the BER / FER performance corresponding to SNR for all the 802 standards within the frequency band are presented. The BER and FER curves are illustrated Figure 11.

Figure 11: BER and FER vs. SNR for 802.15.4g Systems (470 - 510MHz band)

### 4.5.2 Coexistence Simulation Results

#### 4.5.2.1 802.15.4p PHY Mode as Victim Receiver

Figure 12, Figure 13, and Figure 14 show the BER/FER performances of the 802.15.4p PHY mode victim receiver corresponding to the distance from the 802.15.4g interferer to the 802.15.4p DSSS victim receiver.

Figure 12: Victim BER/FER vs. Distance from Interferer Tx to 802.15.4p DSSS Victim Rx

Figure 13: Victim BER/FER vs. Distance from Interferer Tx to 802.15.4p FSK Victim Rx (100 kHz)

Figure 14: Victim BER/FER vs. Distance from Interferer Tx to 802.15.4p FSK Victim Rx (200 kHz)

#### 4.5.2.2 802.15.4g PHY Modes as Victim Receiver

Figure 15 and Figure 16 show the BER/FER performances of the 802.15.4g victim receivers corresponding to the distance from the 802.15.4p interferer to 802.15.4g victim receivers.

Figure 15: Victim BER/FER vs. Distance from Interferer Tx to 802.15.4g Victim Rx

Figure 16: Victim BER/FER vs. Distance from Interferer Tx to 802.15.4g Victim Rx

## 4.6 779 – 787 MHz Band Coexistence Performance

This sub-clause presents the coexistence performance of the systems coexisting in the 779 – 787 MHz frequency band. In order to understand the impact of the generated interference, 802.15.4p systems and other coexisting 802 systems in this frequency band MHz band are set as both the victim and interferer source.

### 4.6.1 Parameters for Coexistence Quantification

The following sub-clauses present the parameters involved in quantification of coexistence analysis amongst the participating systems.

#### 4.6.1.1 PHY Mode Parameters of Coexisting Standards

Table 13 shows the PHY mode parameters of coexisting standards within the frequency band.

Major Parameters of Coexisting 802 Systems in the 779 - 787 MHz Band

#### 4.6.1.2 BER / FER for PHY Modes of Coexisting 802 Standards

In this sub-clause, the BER / FER performance corresponding to SNR for the all the 802 standards within the frequency band are presented. The BER and FER curves are illustrated Figure 17.

Figure 17: BER vs. SNR for 802.15.4 & 4g Systems (779 – 787MHz band)

Figure 18: FER vs. SNR for 802.15.4 & 4g Systems (779 – 787MHz band)

### 4.6.2 Coexistence Simulation Results

#### 4.6.2.1 802.15.4p PHY Mode as Victim Receiver

Figure 30, Figure 36, and Figure 37 show the BER/FER performance of the 802.15.4p PHY mode victim receiver corresponding to the distance from the interferer to the 802.15.4p victim receiver.

Figure 19: Victim BER/FER vs. Distance from Interferer Tx to 802.15.4p DSSS Victim Rx

Figure 20: Victim BER/FER vs. Distance from Interferer Tx to 802.15.4p FSK Victim Rx (100 kHz)

Figure 21: Victim BER/FER vs. Distance from Interferer Tx to 802.15.4p FSK Victim Rx (200 kHz)

#### 4.6.2.2 802.15.4/4g PHY Modes as Victim Receiver

Figure 22 and Figure 23 show the BER/FER performances of the 802.15.4/4g victim receivers corresponding to the distance from the 802.15.4p interferer to the victim receiver.

Figure 22: Victim BER/FER vs. Distance from Interferer Tx to 802.15.4 & 4g Victim Rx

Figure 23: Victim BER/FER vs. Distance from Interferer Tx to 802.15.4 & 4g Victim Rx

## 4.7 863 – 870 MHz Band Coexistence Performance

This sub-clause presents the coexistence performance of the systems coexisting in the 863 - 870 MHz frequency band. In order to understand the impact of the generated interference, 802.15.4p systems and other coexisting 802 systems in this frequency band are set as both the victim and interferer source.

### 4.7.1 Parameters for Coexistence Quantification

The following sub-clauses present the parameters involved in quantification of coexistence analysis amongst the participating systems.

#### 4.7.1.1 PHY Mode Parameters of Coexisting Standards

Table 14 shows the PHY mode parameters of coexisting standards within the frequency band

Table 14: Major Parameters of Coexisting 802 Systems in the 863 - 870 MHz Band

#### 4.7.1.2 BER / FER for PHY Modes of Coexisting 802 Standards

In this sub-clause, the BER / FER performance corresponding to SNR for all the 802 standards within the frequency band are presented. The BER and FER curves are illustrated Figure 24.

Figure 24: BER and FER vs. SNR for 802.15.4 & 4g Systems (863 - 870MHz band)

### 4.7.2 Coexistence Simulation Results

#### 4.7.2.1 802.15.4p PHY Mode as Victim Receiver

Figure 25, Figure 26, and Figure 27 show the BER/FER performances of the 802.15.4p PHY mode victim receiver corresponding to the distance from the interferer to the 802.15.4p victim receiver with bandwidth of 100kHz and 200kHz for FSK.

Figure 25: Victim BER/FER vs. Distance from Interferer Tx to 802.15.4p DSSS Victim Rx

Figure 26: Victim BER/FER vs. Distance from Interferer Tx to 802.15.4p FSK Victim Rx (100 kHz)

Figure 27: Victim BER/FER vs. Distance from Interferer Tx to 802.15.4p FSK Victim Rx (200 kHz)

#### 4.7.2.2 802.15.4/4g PHY Modes as Victim Receiver

Figure 28 and Figure 29 show the BER/FER performances of the 802.15.4/4g victim receivers corresponding to the distance from the 802.15.4p interferer to the 802.15.4/4g victim receivers.

Figure 28: Victim BER/FER vs. Distance from Interferer Tx to 802.15.4 and 802.15.4 & 4g Victim Rx

Figure 29: Victim BER/FER vs. Distance from Interferer Tx to 802.15.4 & 4g Victim Rx

## 4.8 902 – 928 MHz Bands Coexistence Performance

This sub-clause presents the coexistence performance of the systems coexisting in the 902 - 928 MHz frequency bands. In order to understand the impact of the generated interference, 802.15.4p systems and other coexisting 802 systems in this frequency band are set as both the victim and interferer source.

### 4.8.1 Parameters for Coexistence Quantification

The following sub-clauses present the parameters involved in quantification of coexistence analysis amongst the participating systems.

#### 4.8.1.1 PHY Mode Parameters of Coexisting Standards

Table 15 shows the PHY mode parameters of coexisting standards within the frequency band

Table 15: Major Parameters of Coexisting 802 Systems in the 902 - 928 MHz Band

Table 16: MR-O-QPSK Parameters for 802.15.4g Systems in the 920 - 928 MHz Band

#### 4.8.1.2 BER / FER for PHY Modes of Coexisting 802 Standards

In this sub-clause, the BER / FER performances corresponding to SNR for all the 802 standards within the frequency band are presented. The BER and FER curves are illustrated Figure 30.

Figure 30: BER and FER vs. SINR for 802.15.4 & 4g Systems (902 - 928 MHz band)

### 4.8.2 Coexistence Simulation Results

#### 4.8.2.1 802.15.4p PHY Mode as Victim Receiver

Figure 31, Figure 32, and Figure 33 show the BER/FER performances of the 802.15.4p PHY mode victim receivers corresponding to the distance from the interferer to 802.15.4p victim receivers with 100kHz and 200kHz bandwidth for FSK.

Figure 31: Victim BER/FER vs. Distance from Interferer Tx to 802.15.4p DSSS Victim Rx

Figure 32: Victim BER/FER vs. Distance from Interferer Tx to 802.15.4p FSK Victim Rx (100 kHz)

Figure 33: Victim BER/FER vs. Distance from Interferer Tx to 802.15.4p FSK Victim Rx (200 kHz)

#### 4.8.2.2 802.15.4/4g PHY Modes as Victim Receiver

Figure 34 and Figure 35 show the FER performances of the 802.15.4/4g victim receivers corresponding to the distance from the 802.15.4p interferer to the 802.15.4/4g victim receiver.

Figure 34: Victim BER/FER vs. Distance from Interferer Tx to 802.15.4 & 4g Victim Rx

Figure 35: Victim BER/FER vs. Distance from Interferer Tx to 802.15.4 & 4g Victim Rx

## 4.9 2400 – 2483.5 MHz Band Coexistence Performance

This sub-clause presents the coexistence performance of the systems coexisting in the 2400 – 2483.5 MHz frequency band. In order to understand the impact of the generated interference, 802.15.4p systems and other coexisting 802 systems in this frequency band MHz band are set as both the victim and interferer source.

### 4.9.1 Parameters for Coexistence Quantification

The following sub-clauses present the parameters involved in quantification of coexistence analysis amongst the participating systems.

#### 4.9.1.1 PHY Mode Parameters of Coexisting Standards

Table 17 shows the PHY mode parameters of coexisting standards within the frequency band

Table 17: Major Parameters of Coexisting 802 Systems in the 2400 – 2483.5 MHz band

#### 4.9.1.2 BER / FER for PHY Modes of Coexisting 802 Standards

In this sub-clause, the BER / FER performance corresponding to SNR for the all the 802 standards within the frequency band are presented. The BER and FER curves are illustrated in Figure 36 and Figure 37.

Figure 36: BER vs. SINR for 802.11 & 802.15 Systems (2400 – 2483.5MHz band)

Figure 37: FER vs. SINR for 802.11 & 802.15 Systems (2400 – 2483.5MHz band)

### 4.9.2 Coexistence Simulation Results

#### 4.9.2.1 802.15.4p PHY Mode as Victim Receiver

Figure 38, Figure 39, Figure 40, and Figure 41 show the BER/FER performances of the 802.15.4p PHY mode victim receivers corresponding to the distance from the 802.11 and 802.15.4/4g interferers to the 802.15.4p victim receiver.

Figure 38: Victim BER vs. Distance from Interferer Tx to 802.15.4p DSSS Victim Rx

Figure 39: Victim FER vs. Distance from Interferer Tx to 802.15.4p DSSS Victim Rx

### 4.9.2.2 802.11 PHY Modes as Victim Receiver

Figure 42, Figure 43, and Figure 44 show the BER/FER performances of the 802.11 victim receivers corresponding to the distance from the 802.15.4p interferer to the 802.11 victim receiver at different interferer’s transmitting power levels.

Figure 40: Victim BER/FER vs. Distance from Interferer Tx (0dBm) to 802.11 Victim Rx

Figure 41: Victim BER/FER vs. Distance from Interferer Tx (15dBm) to 802. 11 Victim Rx

Figure 42: Victim BER/FER vs. Distance from Interferer Tx (30dBm)to 802. 11 Victim Rx

#### 4.9.2.3 802.15 PHY Modes as Victim Receiver

Figure 45, Figure 46, Figure 47, Figure 48, Figure 49, Figure 50, Figure 51, Figure 52, Figure 53, Figure 54, Figure 55, and Figure 56 show the BER/FER performances of the 802.15 victim receivers corresponding to the distance from the 802.15.4p interferer to the 802.15 victim receivers at different interferer’s transmitting power levels.

Figure 43: Victim BER vs. Distance from Interferer Tx (0dBm) to 802.15 Victim Rx

Figure 44: Victim BER vs. Distance from Interferer Tx (15dBm) to 802.15 Victim Rx

Figure 45: Victim BER vs. Distance from Interferer Tx (30dm) to 802.15 Victim Rx

Figure 46: Victim FER vs. Distance from Interferer Tx (0dBm) to 802.15 Victim Rx

Figure 47: Victim FER vs. Distance from Interferer Tx (15dBm) to 802.15 Victim Rx

Figure 48: Victim FER vs. Distance from Interferer Tx (30dBm) to 802.15 Victim Rx

# 5 Interference Avoidance and Mitigation Techniques

802.15.4p adopts the interference avoidance and mitigation techniques outlined in 802.15.4g coexistence document (B10).

# 6 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 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.