IEEE P802.15
Wireless Personal Area Networks

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Re:		
Abstract	Analysis on coexistence of 802.15.4k with other 802 systems within the same spectrum bands	
Purpose	To address the coexistence capability of 802.15.4k	
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Release	The contributor acknowledges and accepts that this contribution becomes the property of IEEE and may be made publicly available by P802.15.	

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1 Introduction

1.1 Bibliography

(B1) IEEE Std. 802.15.1™ – 2005, IEEE Standard for Information Technology – Telecommunications and Information exchange between systems – Local and metropolitan area networks – Specific requirements – Part 15.1: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Wireless Personal Area Networks (WPANs).

(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).

(B4) IEEE Std. 802.15.4™ – 2011, 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).

(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 (LR-WPANs) Amendment to the MAC sub-layer.

(B6) IEEE Std. 802.15.4k /D6 – 2012, IEEE Draft 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 x: Physical Layer Specifications for Low Energy, Critical Infrastructure Monitoring Networks.

(B7) IEEE Std. 802.15.4g™ - 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 3: Physical Layer Specifications for Low Data Rate Wireless Smart Metering Utility Network.

(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. 802.15.4k TG4k PAR (IEEE 802.15.11-0061-00-004k)

2 Overview

The overview of 802.15.4k is summarized in Section 5.2 Scope of TG4k PAR (B12).

2.1 Regulatory Information

The allocated frequency bands for 802.15.4k are given as below:

(a) 169.400 – 169.475 MHz (Europe)
(b) 433.050 – 434.790 MHz (North America / Europe)
(c) 470 – 510 MHz (China)
(d) 779 – 787 MHz (China)
(e) 863 – 870 MHz (Europe)
(f) 902 – 928 MHz (Americas)
(g) 915 – 928 MHz (Australia)
(h) 917 – 923.5 MHz (Korea)
(i) 920.5 – 923.5 MHz (Japan)
(j) 921 – 928 MHz (New Zealand)
(k) 2400 – 2483.5 MHz (Worldwide)

From the above list bands (c) **–** (k) may be occupied by both 802.15.4k PHYs. These are listed in Table 1, below.

Table 1: Frequency Bands for 802.15.4k PHYs

Frequency Band (MHz)	IEEE 802.15.4k PHYs	
	FSK	DSSS
169.400 – 169.475 MHz (Europe)	X	
433.050 – 434.790 MHz (North America / Europe)	X	
470 – 510 MHz (China)	X	X
779 – 787 MHz (China)	X	X
863 – 870 MHz (Europe)	X	X
902 – 928 MHz (Americas)	X	X
915 – 928 MHz (Australia)	X	X
917 – 923.5 MHz (Korea)	X	X
920.5 – 923.5 MHz (Japan)	X	X
921 – 928 MHz (New Zealand)	X	X
2400 – 2483.5 MHz (Worldwide)		X

2.2 Overview of Coexistence Mechanisms in 802.15.4 and 802.15.4k

The importance of coexistence mechanism in LECIM is two-fold. LECIM specifies two alternative PHYs that shall be able to coexist with each other if operating co-located in the same frequency band. LECIM 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 LECIM PHYs) and heterogeneous (across other 802 systems) coexistence.

3 Dissimilar Systems Sharing the Same Frequency Bands with 802.15.4k

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

The frequency bands of interest are the 169.4 - 169.475 MHz Band, 433.05 – 434.79 MHz band, 470 – 510 MHz band, 779 – 787 MHz band, 863 – 870 MHz band, frequency bands between 902 – 928 MHz (bands (f) of sub-clause 2.1) and 2400 – 2483.5MHz.

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:

(a) Standard specification: the name of the 802 system with which 802.15.4k system is coexisting
(b) PHY specification: the PHY design of the above 802 system specification
(c) Receiver bandwidth: the receiver bandwidth of the above 802 system specification
(d) Transmit power: the transmit power of the above 802 system specification
(e) Receiver sensitivity: the receiver sensitivity of the above 802 system specification.
(f) Involved 802.15.4k system: the particular PHY in 802.15.4k 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 169.4 - 169.475 MHz Band

Table 2 shows other 802 systems that share the 169.4 - 169.475 MHz band with 802.15.4k PHYs.

Table 2: Dissimilar Systems coexisting with 802.15.4k within 169.4 - 169.475 MHz band

Standard	Standard PHY Specification	Involved 802.15.4k PHY
802.15.4g	MR-FSK	FSK

3.2 Coexisting Systems in 433.05 – 434.79 MHz Band

Table 3 shows other 802 systems that share the 434.05 – 434.79 MHz band with 802.15.4k PHYs.

Table 3: Dissimilar Systems coexisting with 802.15.4k within 433.05 - 434.79 MHz band

Standard	Standard PHY Specification	Involved 802.15.4k PHY
802.15.4f	MSK	FSK

3.3 Coexisting Systems in 470 – 510 MHz Band

Table 4 shows other 802 systems that share the 470 - 510 MHz band with 802.15.4k PHYs.

Table 4: Dissimilar Systems coexisting with 802.15.4k within 470 – 510 MHz band

Standard	Standard PHY Specification	Involved 802.15.4k PHY
802.15.4g	MR-FSK	FSK DSSS
	MR-OFDM	
	MR-O-QPSK	

3.4 Coexisting Systems in 779 - 787 MHz Band

Table 5 shows other 802 systems that share the 779 - 787 MHz band with 802.15.4k PHYs.

Table 5: Dissimilar Systems coexisting with 802.15.4k within 470 – 510 MHz band

Standard	Standard PHY Specification	Involved 802.15.4k PHY
802.15.4	O-QPSK	FSK DSSS
	MPSK	
802.15.4g	MR-FSK	
	MR-OFDM	
	MR-O-QPSK	

3.5 Coexisting Systems in 863 – 870 MHz Band

Table 6 *shows other 802 systems that share the 863 – 870 MHz band with 802.15.4k PHYs*

Table 6: Dissimilar Systems coexisting with 802.15.4k within 863 - 870 MHz band

Standard	Standard PHY Specification	Involved 802.15.4k PHY
802.15.4	BPSK	FSK DSSS
	ASK	
	O-QPSK	
802.15.4g	MR-FSK	
	MR-OFDM	
	MR-O-QPSK	

3.6 Coexisting Systems in 902 – 928 MHz Bands

Table 7 shows other 802 systems that share the 902 – 928 MHz bands with 802.15.4k PHYs

Table 7: Dissimilar Systems coexisting with 802.15.4k within 902 - 928 MHz band

Standard	Standard PHY Specification	Involved 802.15.4k PHY
802.15.4	BPSK	FSK DSSS
	ASK	
	O-QPSK	
802.15.4g	MR-FSK	
	MR-OFDM	
	MR-O-QPSK	

3.7 Coexisting Systems in 2400 – 2483.5 MHz Band

Table 8 shows other 802 systems that share the 2480 – 2483.5 MHz band with 802.15.4k PHYs

Table 8: Dissimilar Systems coexisting with 802.15.4k within 2400 – 2483.5 MHz band

Standard	Standard PHY Specification	Involved 802.15.4k PHY
802.15.4	O-QPSK	DSSS
	CSS	
802.15.4f	MSK	
802.15.4g	MR-FSK	
	MR-OFDM	
	MR-O-QPSK	
802.15.1	FHSS GFSK	
802.15.3	SC D-QPSK	
802.11b	DSSS	
802.11g	DSSS	
	OFDM	
802.11n	OFDM	

4 Coexistence Scenario and Analysis

4.1 PHY Modes in the 802.15.4k System

4.1.1 Parameters of the 802.15.4k 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 802.15.4k PHY Modes

System	PHY	PHY Mode	Channel Spacing (kHz)	Transmit Power (dBm) [1]	Receiver Sensitivity[2] (dBm)	Average Frame Length (Octet)
802.15.4k	FSK	25 kb/s FSK[3]	-50 (169MHz band) -100 (all except 169MHz and 2.4GHZ band) -200 (all except 169MHz band)	0/15/30	-90	250
	DSSS	1000 kc/s O-QPSK[4]	1000	0/15/30	-90	20

4.1.2 BER / FER Calculations for 802.15.4k 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 802.15.4k 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 802.15.4k PHY modes with different spreading factors in 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.

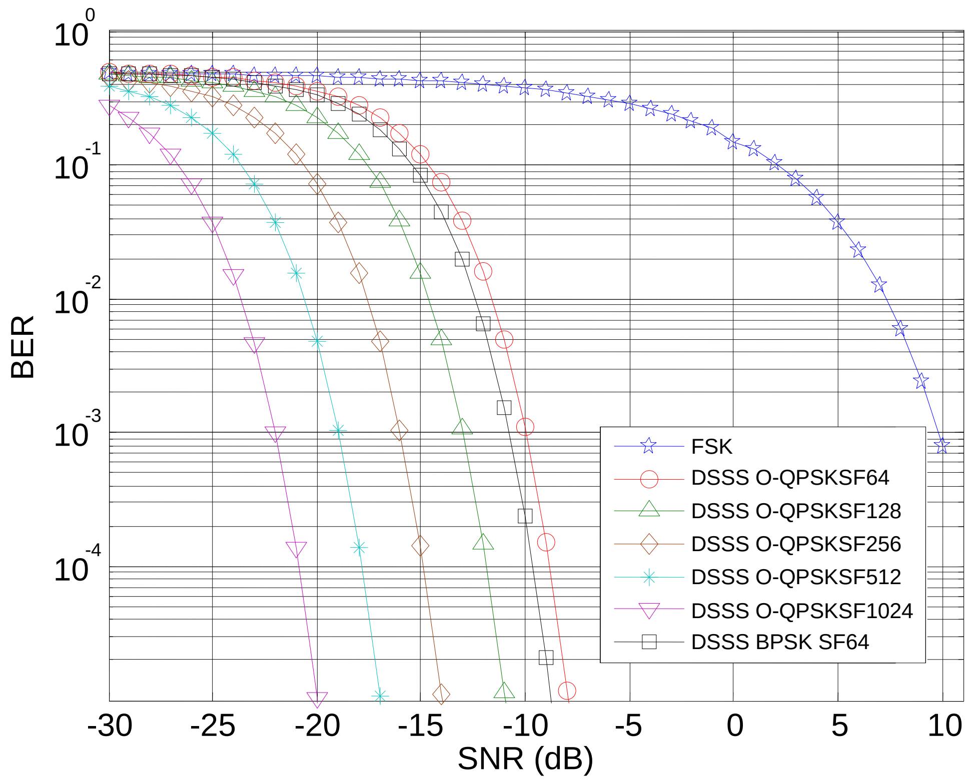

Figure 1: BER vs. SNR for 802.15.4k FSK and DSSS

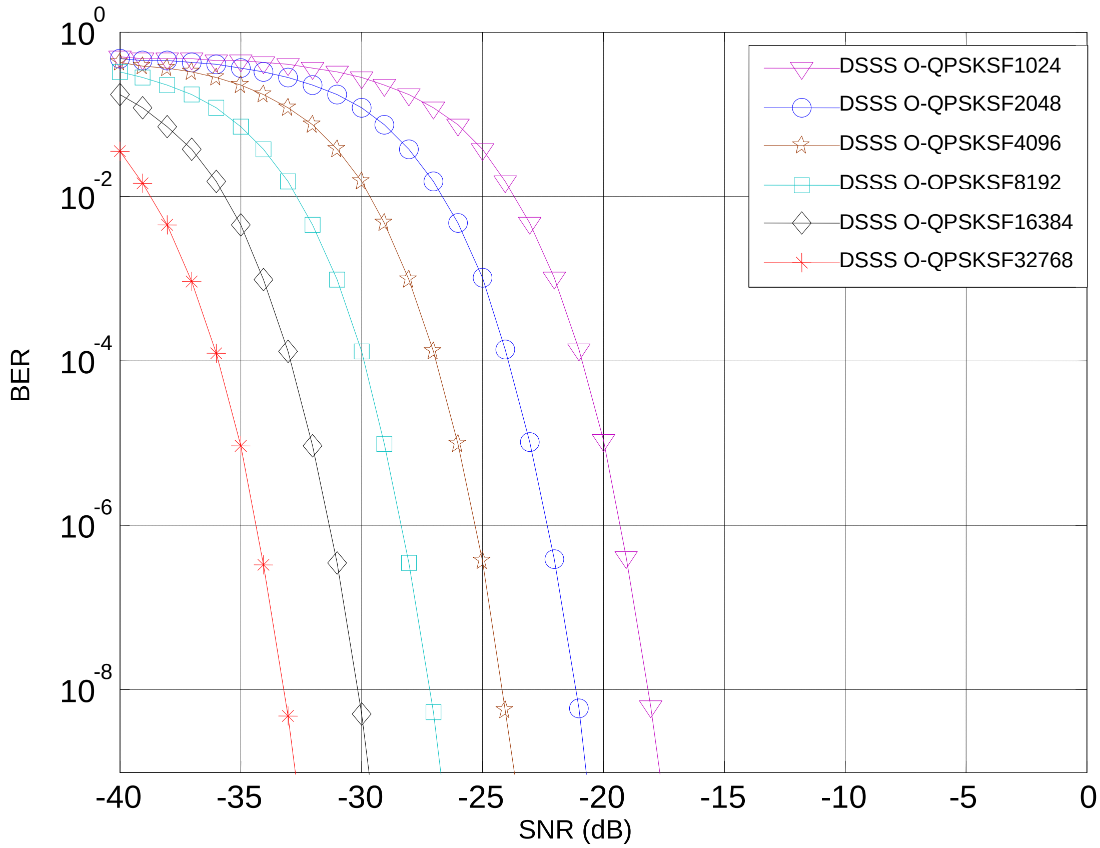

Figure 2: BER vs. SNR for 802.15.4k DSSS

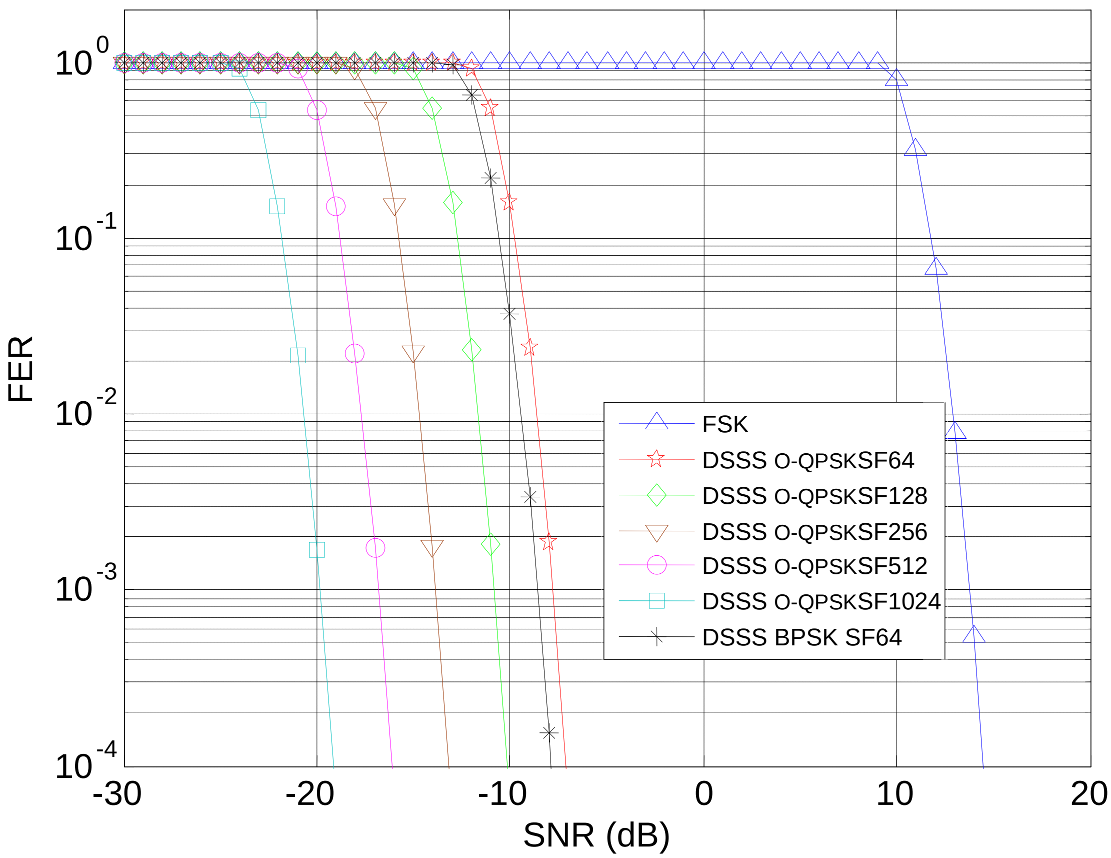

Figure 3: FER vs. SNR for 802.15.4k FSK and DSSS

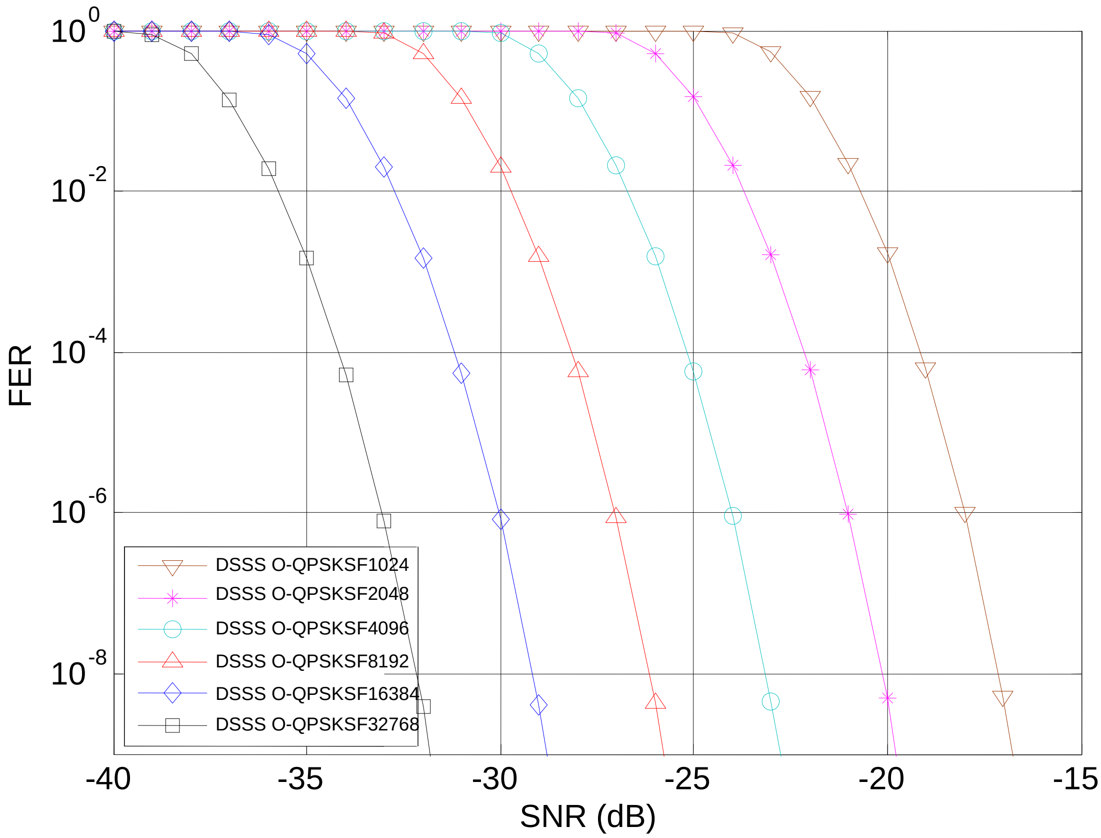

Figure 4: FER vs. SNR for 802.15.4k DSSS

4.2 Interference Modeling

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

- In the coexistence model, the transmitting power and distance between the victim's transmitter and receiver are fixed, thus the 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 centre frequency and the victim's centre frequency in the spectrum. This assumes worst case - centre freq 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 802.15.4k DSSS PHY, O-QPSK and spreading factor of 64 are used for the worst case.
- Unless specifically mentioned, Tx power 0dBm is used for 802.15.4k as victim and 15dBm for 802.15.4k 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, 802.15.4k 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

System	PHY Spec	PHY Mode	Channel Bandwidth (kHz)	Transmit Power (dBm)	Receiver Sensitivity (dBm)
802.15.4g	MR-FSK	FSK 4.8 kb/s, h = 0.5	12.5	0	-101

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 802.15.4k FSK are used for FER calculation.

The BER and FER curves are illustrated in Figure **5**.

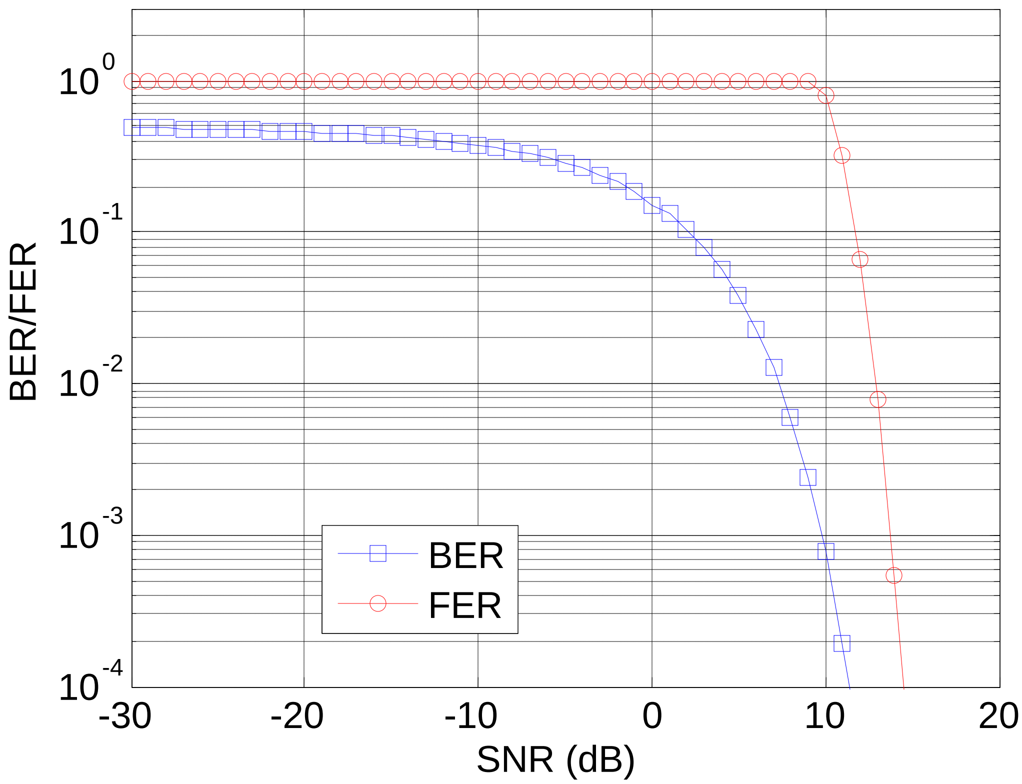

Figure 5: BER/FER vs. SNR for 802.15.4g MR-FSK (169.400 - 169.475MHz band)

4.3.2 Coexistence Simulation Results

4.3.2.1 802.15.4k PHY Mode as Victim Receiver

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

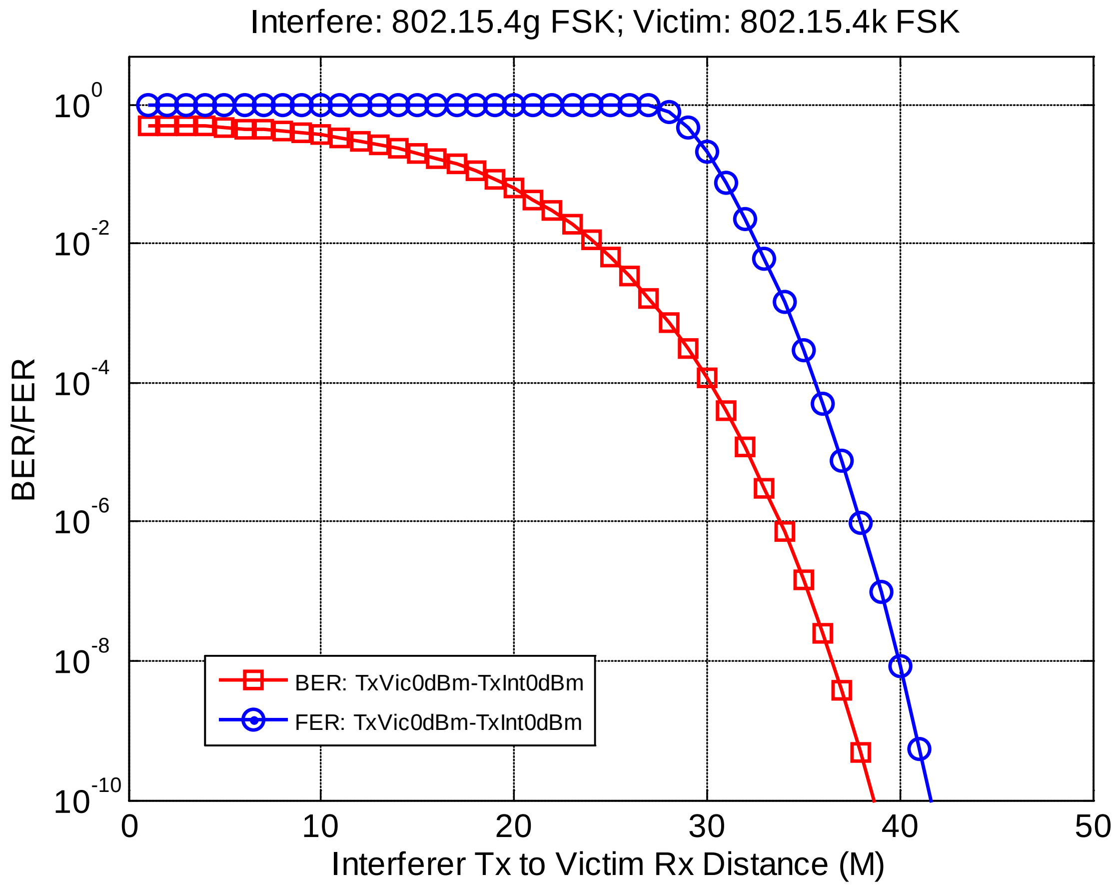

Figure 6: Victim BER/FER vs. Distance from Interferer Tx to 802.15.4k FSK Victim Rx

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 802.15.4k 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.

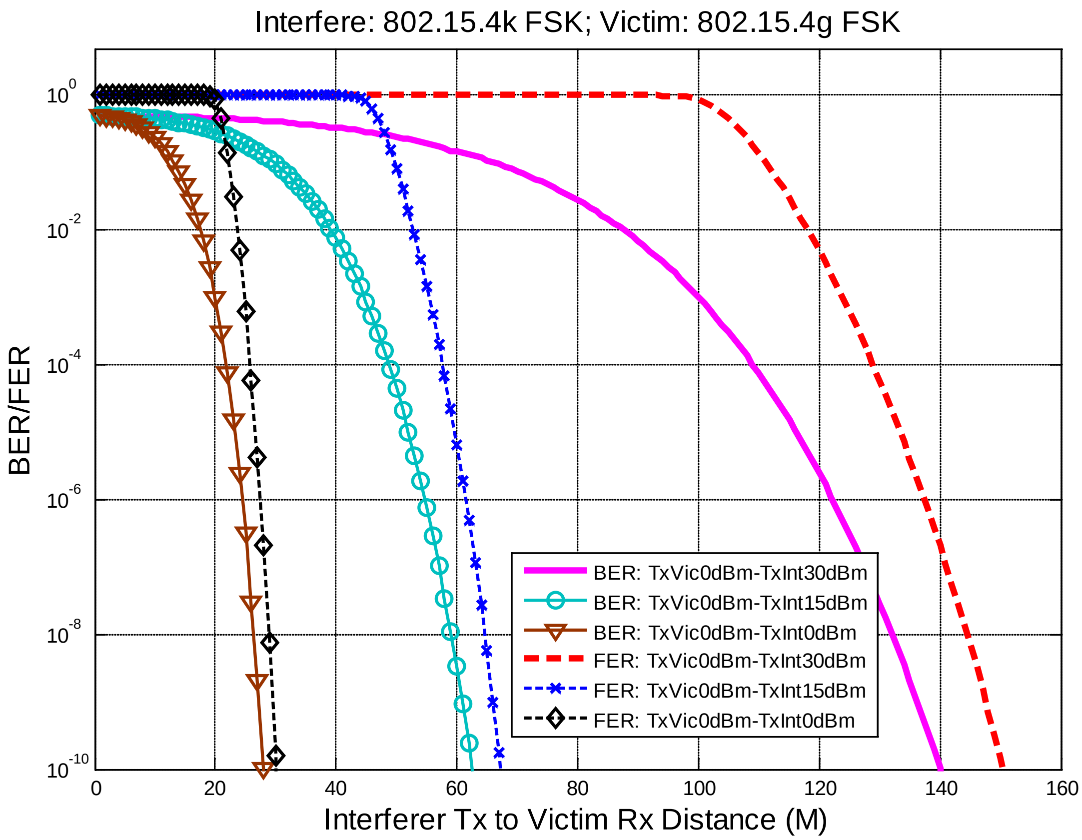

Figure 7: Victim BER/FER vs. Distance from Interferer Tx to 802.15.4g MR-FSK Victim Rx

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, 802.15.4k 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

System	PHY Spec	PHY Mode	Channel Bandwidth (kHz)	Transmit Power (dBm)	Receiver Sensitivity (dBm)
802.15.4f	MSK	MSK 250 kb/s	580	0	-

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 802.15.4k FSK for FER calculation.

The BER and FER curves are illustrated in Figure **8**.

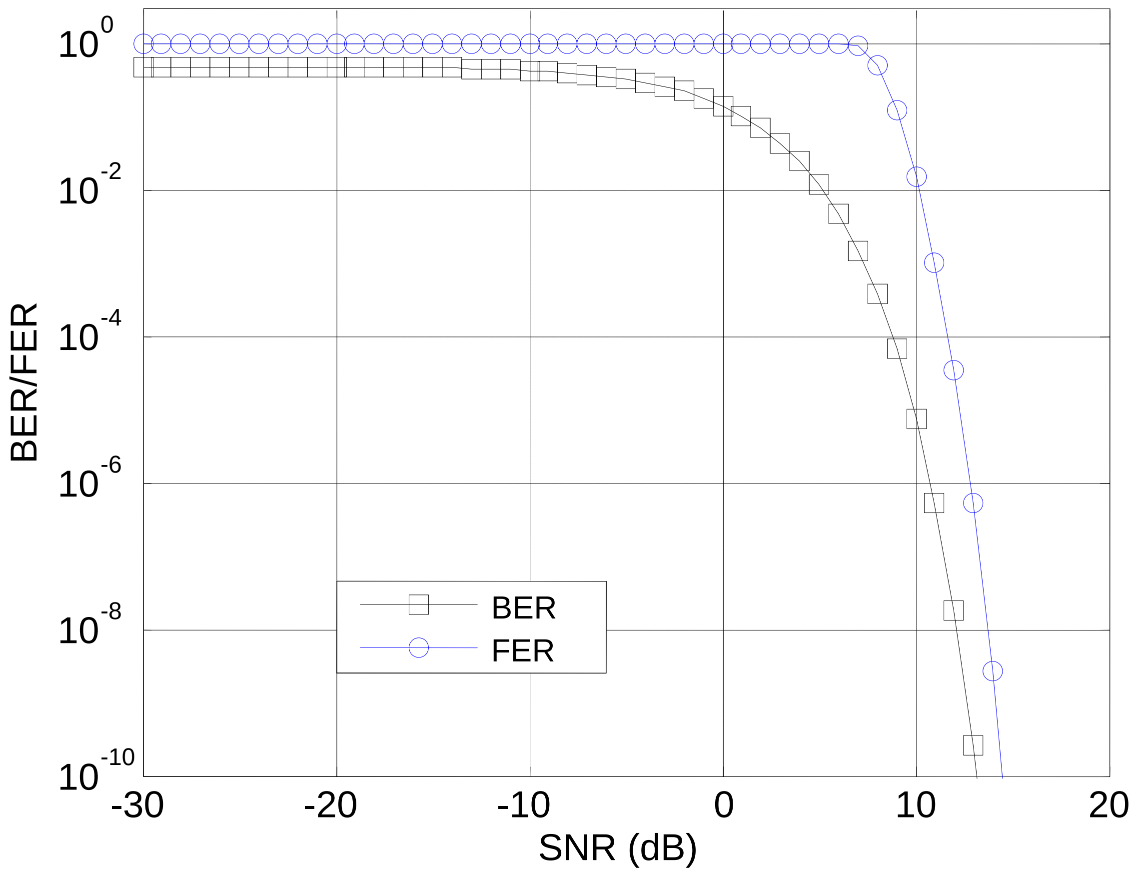

Figure 8: BER/FER vs. SNR for 802.15.4f (433.05 – 434.79MHz band)

4.4.2 Coexistence Simulation Results

4.4.2.1 802.15.4k PHY Mode as Victim Receiver

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

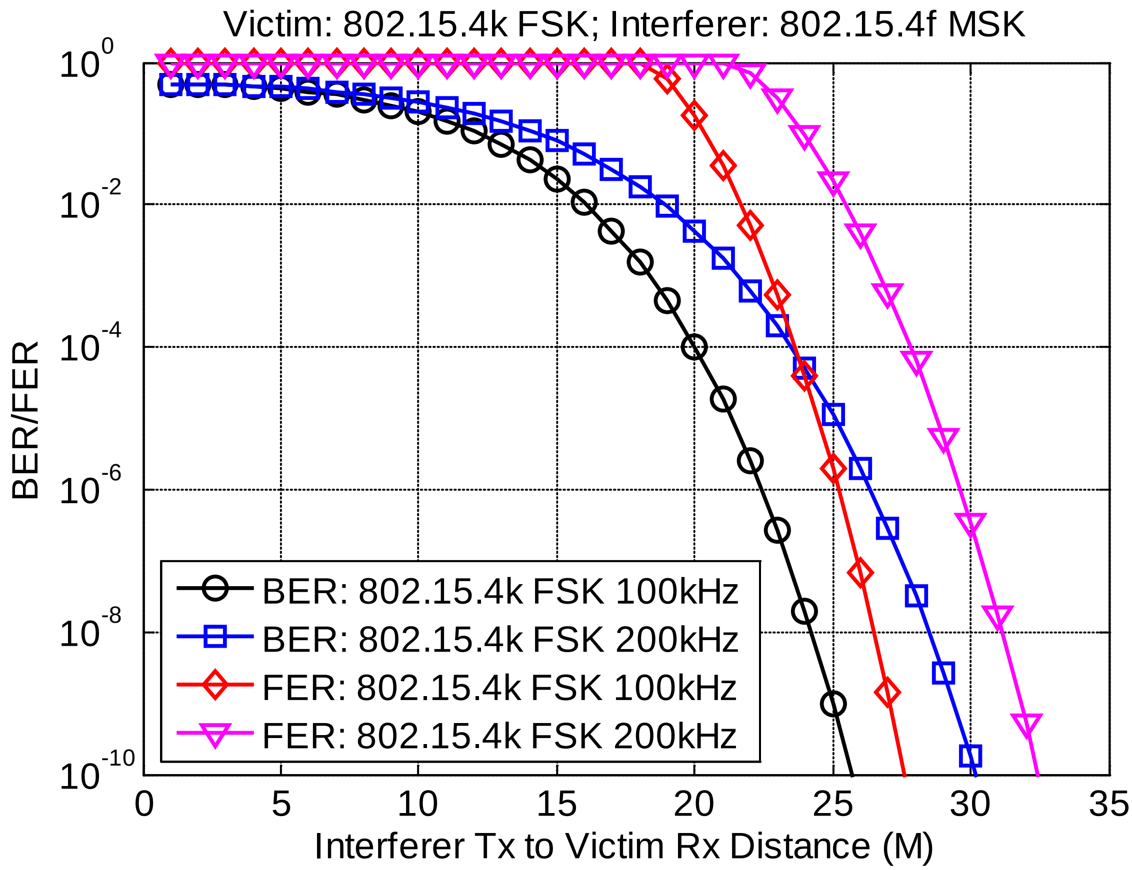

Figure 9: Victim BER/FER vs. Distance from Interferer Tx to 802.15.4k FSK Victim Rx

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 802.15.4k interferer to the 802.15.4g victim receiver. 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.

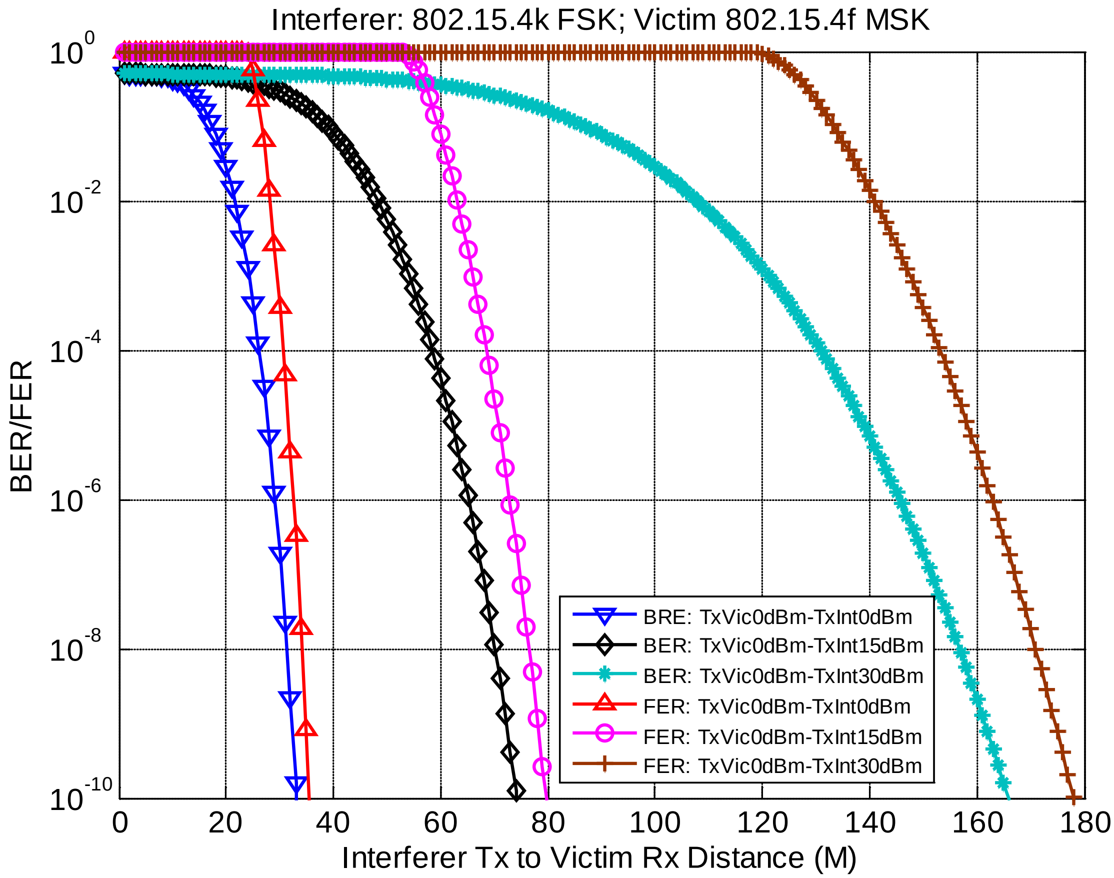

Figure 10: Victim BER/FER vs. Distance from Interferer Tx to 802.15.4f MSK Victim Rx

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, 802.15.4k 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

System	PHY Spec	PHY Mode	Channel Bandwidth (kHz)	Transmit Power (dBm)	Receiver Sensitivity (dBm)	Average Frame Length (Octet)
802.15.4g	MR-FSK	FSK 50 kb/s, h = 1.0	200	0	-91	250
	MR-OFDM	QPSK, 100 kb/s OFDM Option 4, MCS3,	200	0	-103	20
	MR-O-QPSK	QPSK, 100 kc/s Rate Mode 3	400	0	-95	20

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.

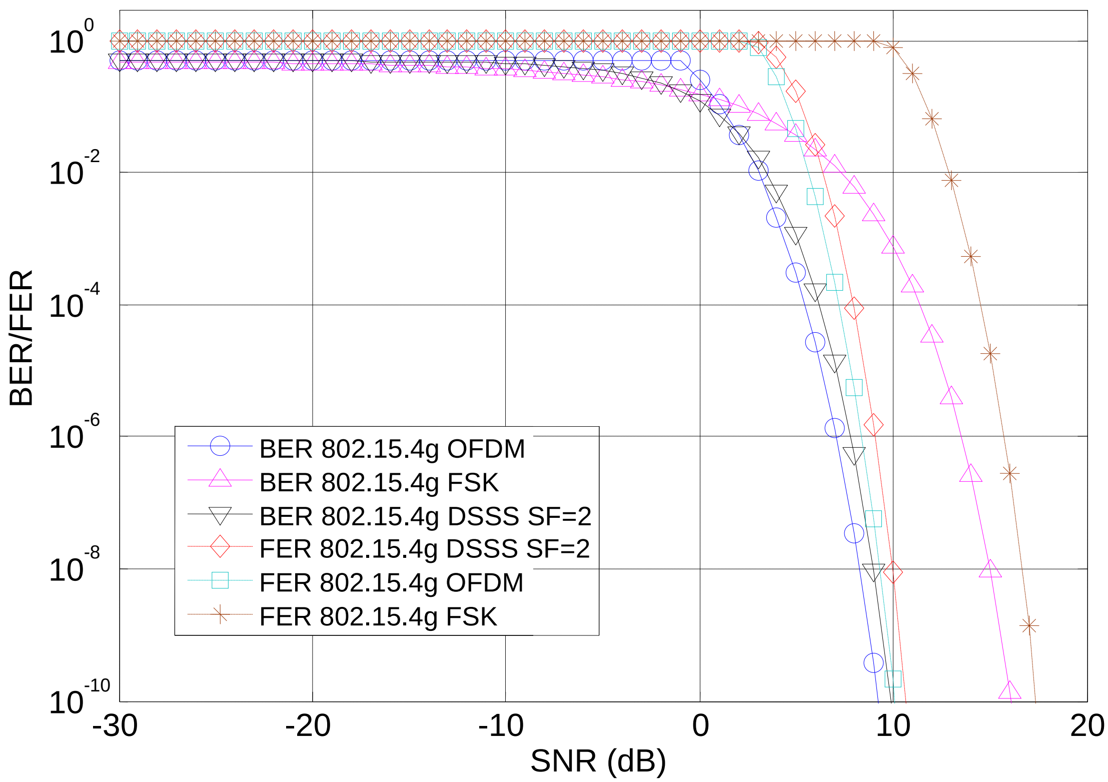

Figure 11: BER and FER vs. SNR for 802.15.4g Systems (470 - 510MHz band)

4.5.2 Coexistence Simulation Results

4.5.2.1 802.15.4k PHY Mode as Victim Receiver

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

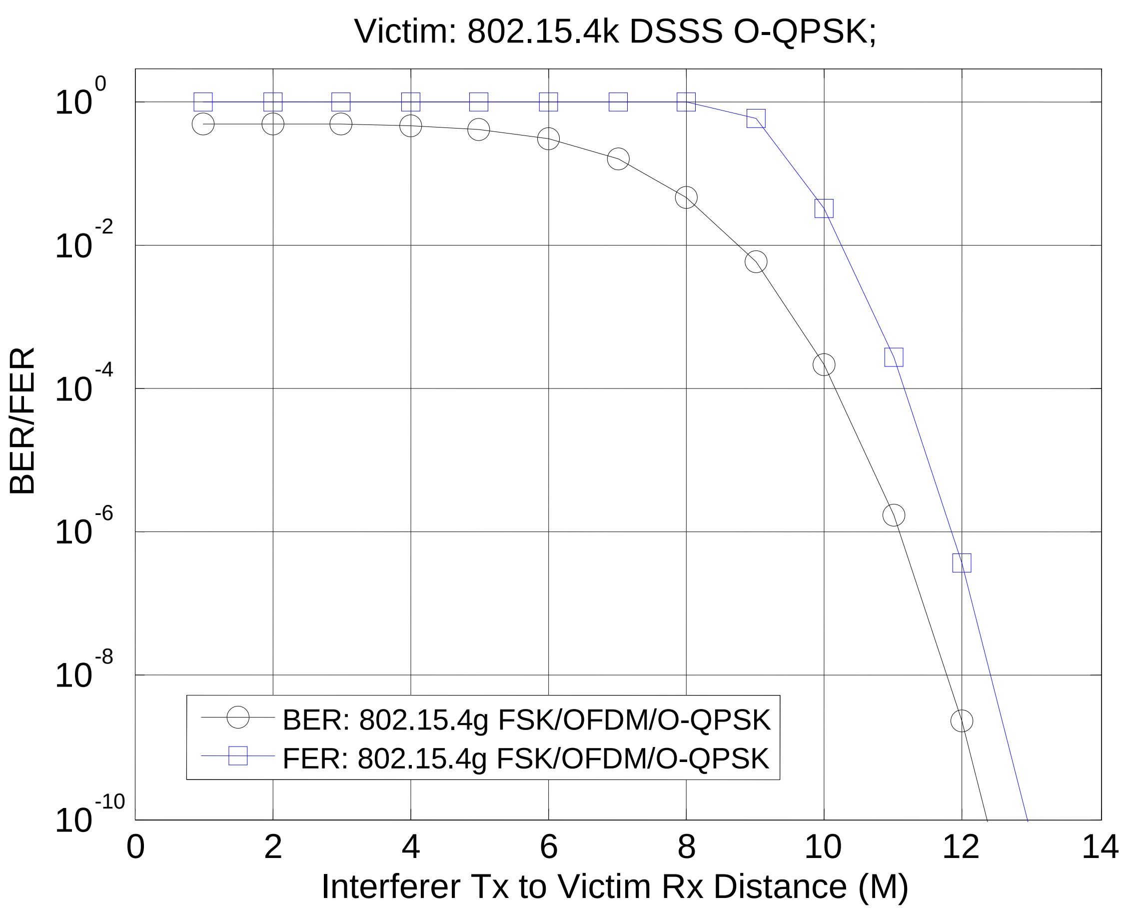

Figure 12: Victim BER/FER vs. Distance from Interferer Tx to 802.15.4k DSSS Victim Rx

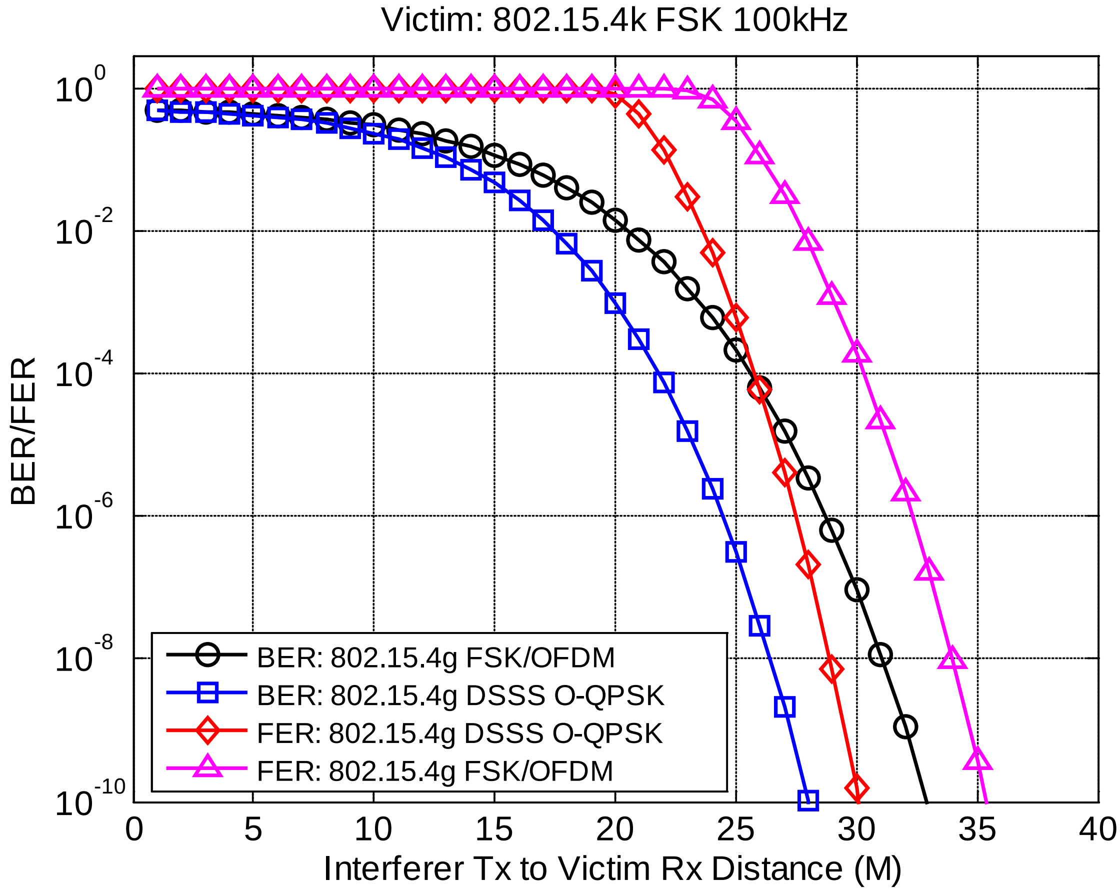

Figure 13: Victim BER/FER vs. Distance from Interferer Tx to 802.15.4k FSK Victim Rx (100 kHz)

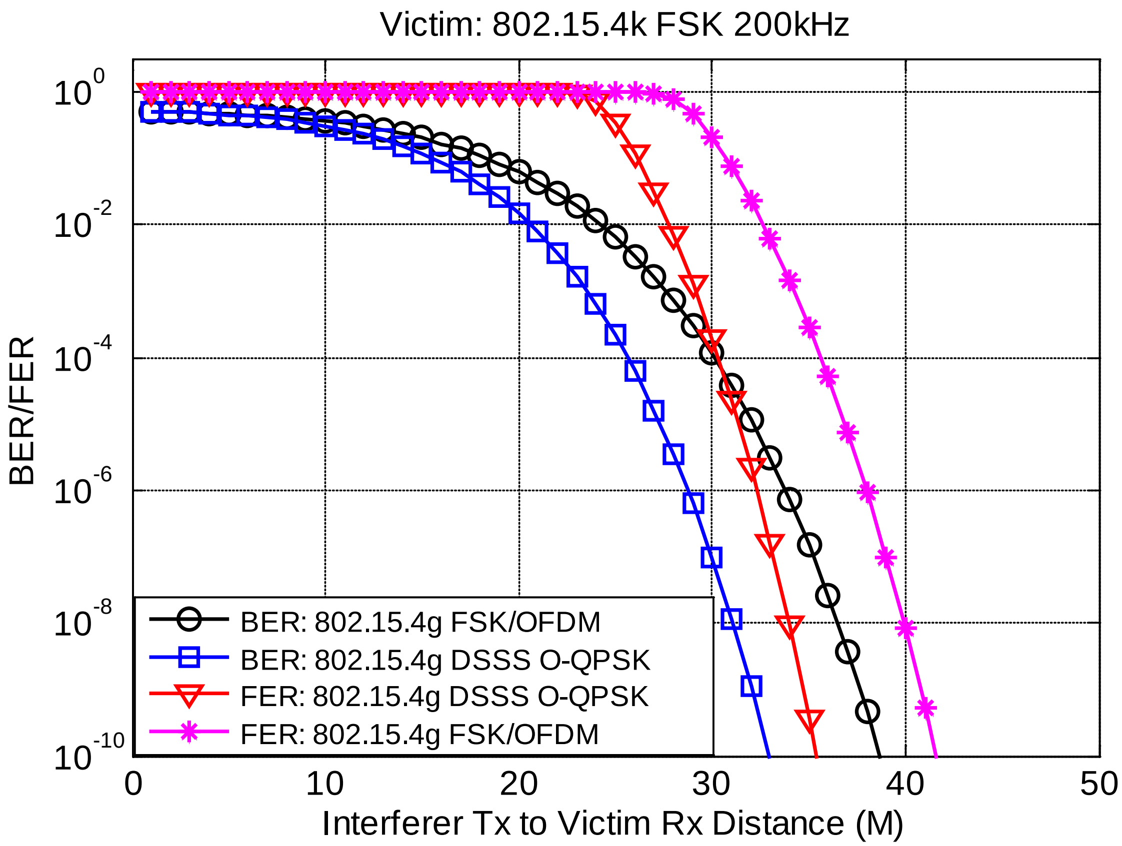

Figure 14: Victim BER/FER vs. Distance from Interferer Tx to 802.15.4k FSK Victim Rx (200 kHz)

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 802.15.4k interferer to 802.15.4g victim receivers.

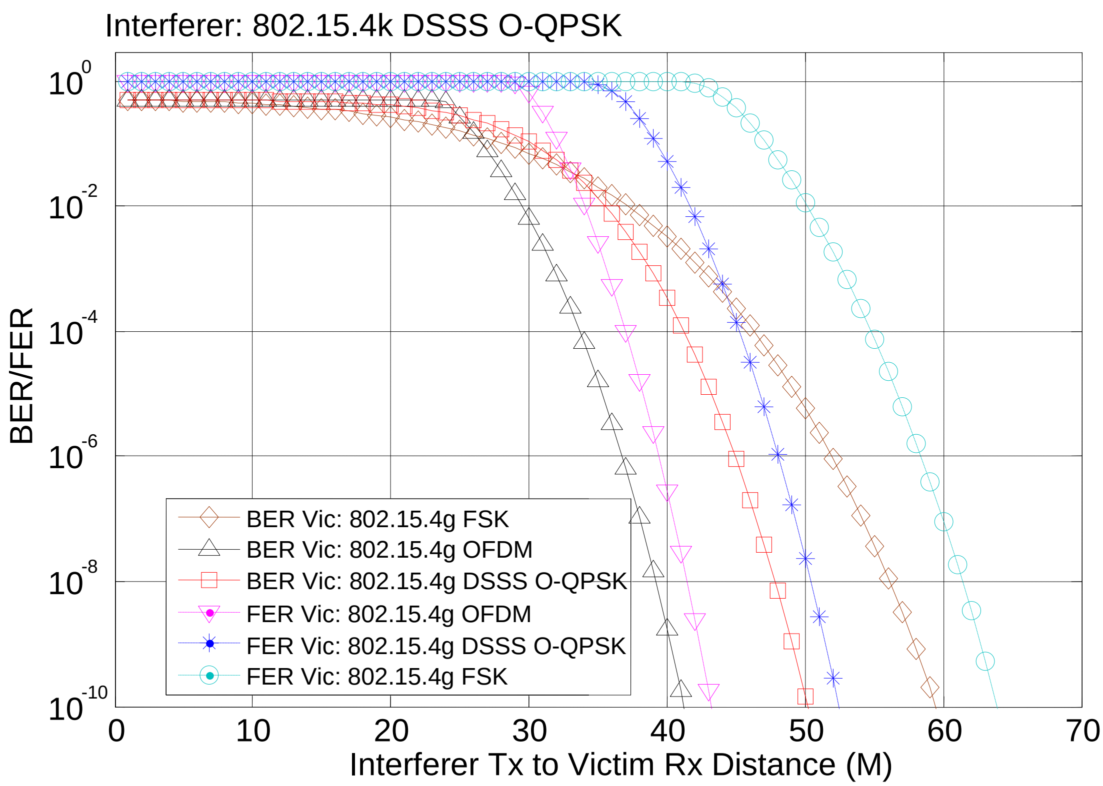

Figure 15: Victim BER/FER vs. Distance from Interferer Tx to 802.15.4g Victim Rx

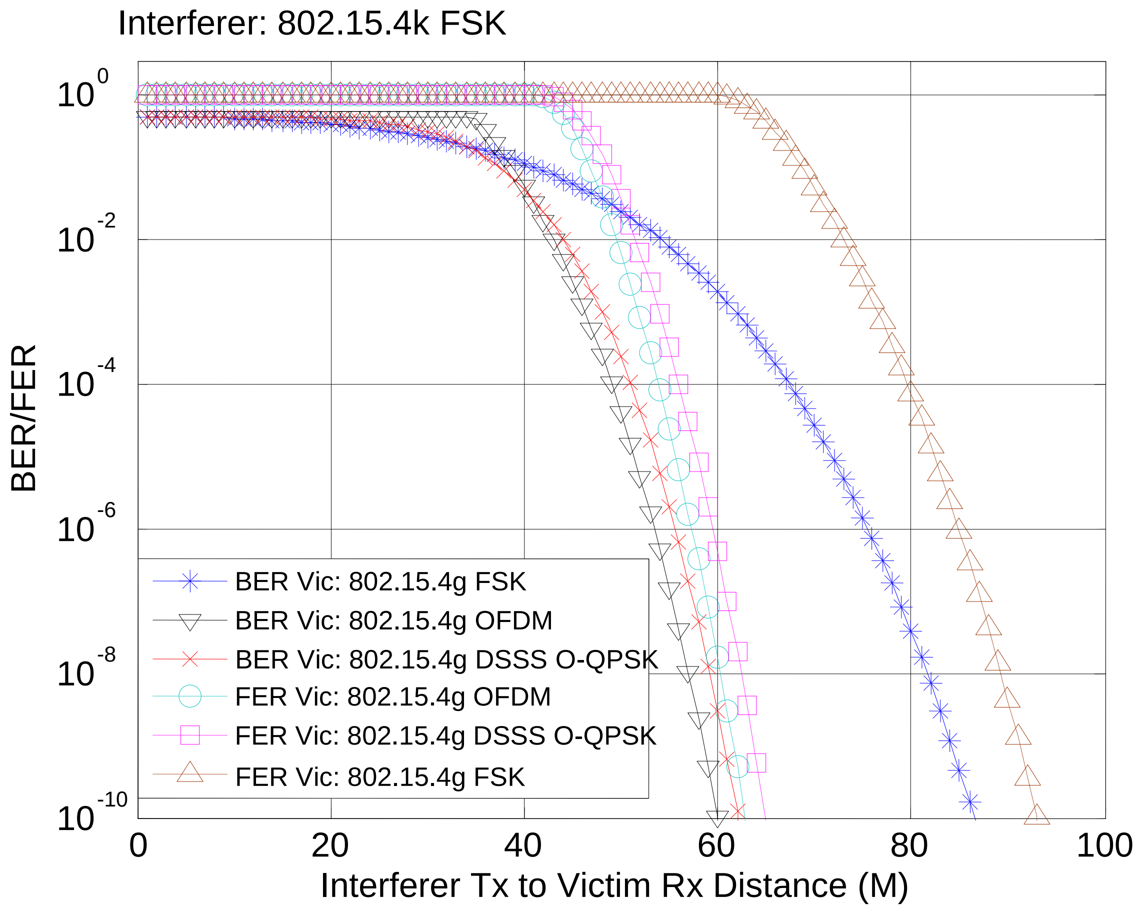

Figure 16: Victim BER/FER vs. Distance from Interferer Tx to 802.15.4g Victim Rx

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, 802.15.4k 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

Table 13: Major Parameters of Coexisting 802 Systems in the 779 - 787 MHz Band

System	PHY Spec	PHY Mode	Channel Bandwidth (kHz)	Transmit Power (dBm)	Receiver Sensitivity (dBm)	Average Frame Length (Octet)
802.15.4	DSSS	O-QPSK 1000 kc/s, 250 kb/s	2000	0	-85	22
	MPSK	MPSK 1000 kc/s, 250 kb/s	2000	0	-85	22
802.15.4g	MR-FSK	FSK 50 kb/s, h = 1.0	200	0	-91	250
	MR-OFDM	QPSK, 100 kb/s OFDM Option 4, MCS3	200	0	-103	20
	MR-O-QPSK	QPSK, 1000 kc/s Rate Mode 3	2000	0	-90	20

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.

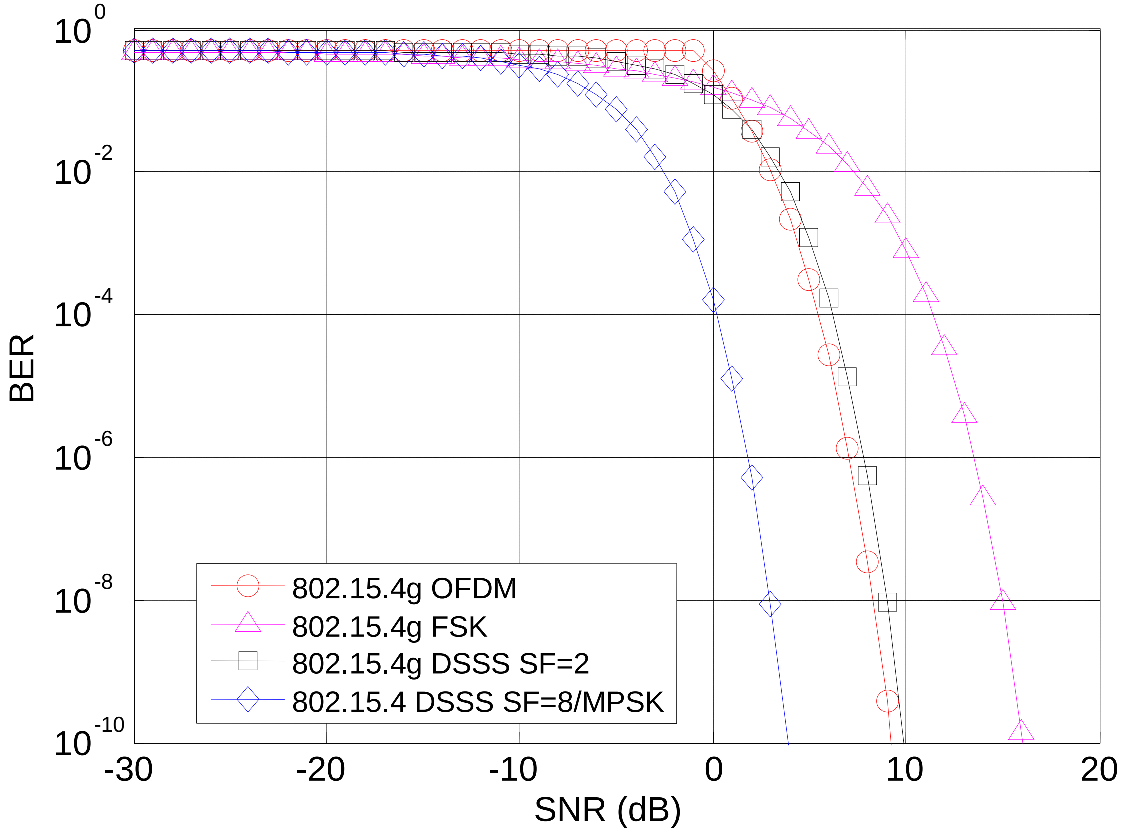

Figure 17: BER vs. SNR for 802.15.4 & 4g Systems (779 – 787MHz band)

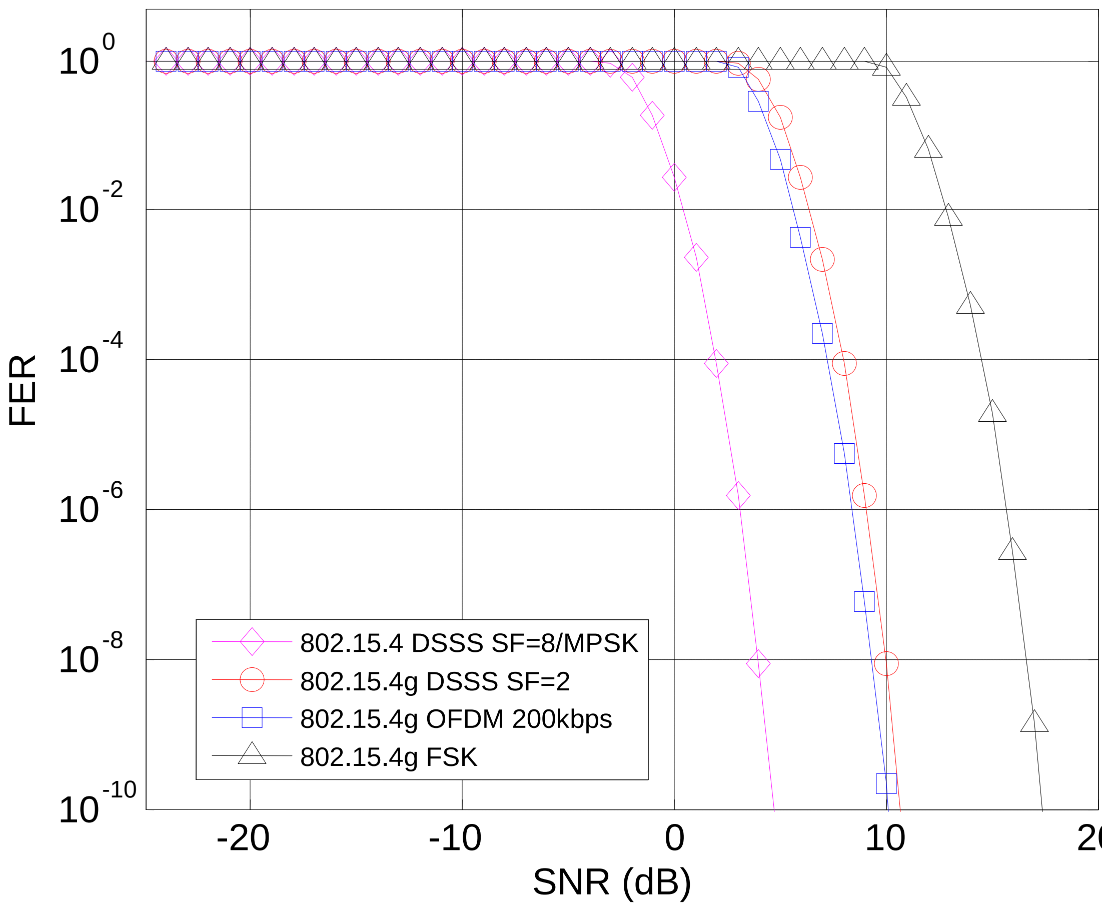

Figure 18: FER vs. SNR for 802.15.4 & 4g Systems (779 – 787MHz band)

4.6.2 Coexistence Simulation Results

4.6.2.1 802.15.4k PHY Mode as Victim Receiver

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

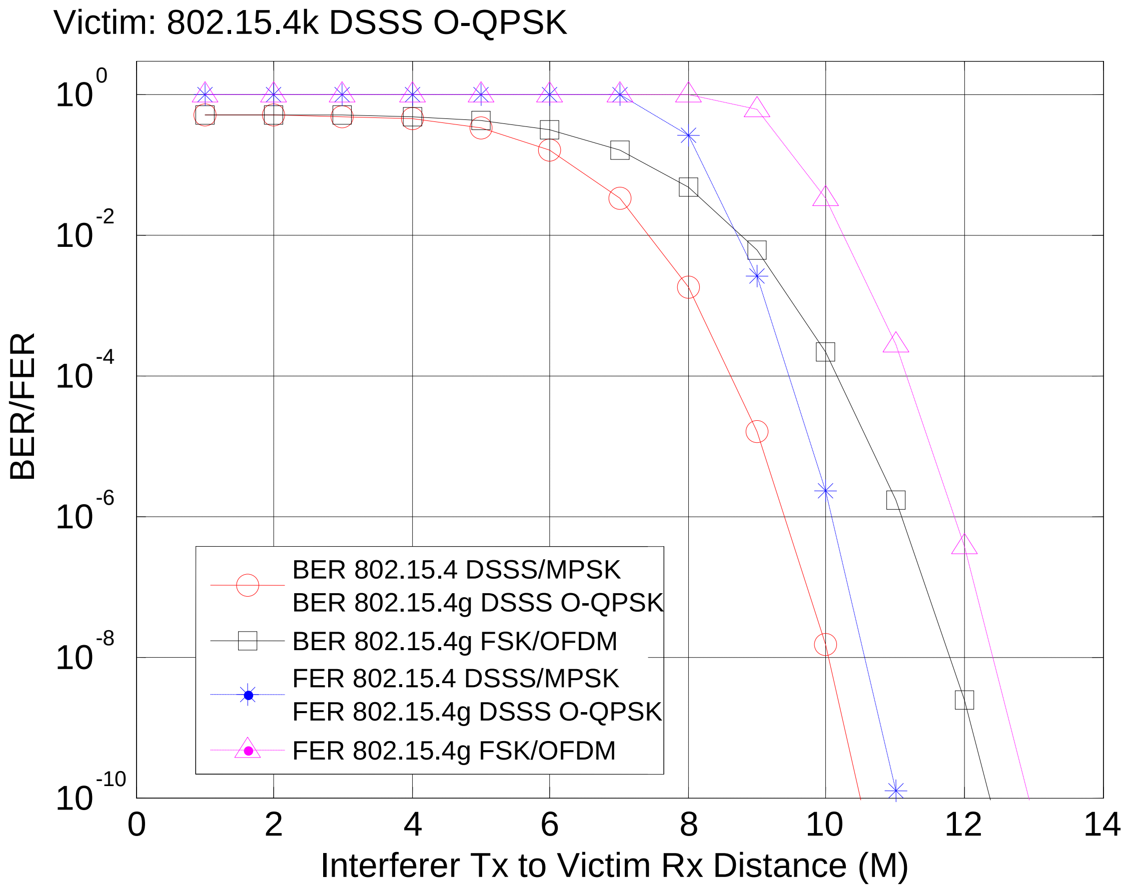

Figure 19: Victim BER/FER vs. Distance from Interferer Tx to 802.15.4k DSSS Victim Rx

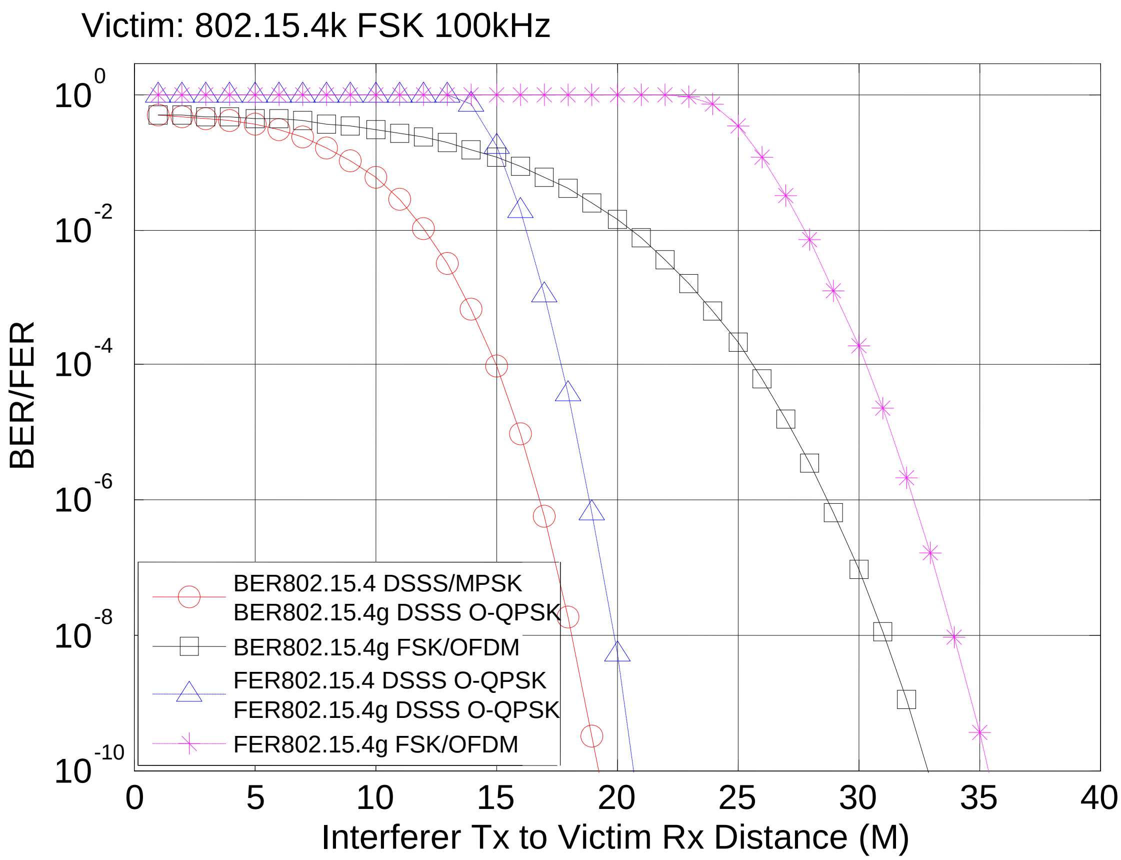

Figure 20: Victim BER/FER vs. Distance from Interferer Tx to 802.15.4k FSK Victim Rx (100 kHz)

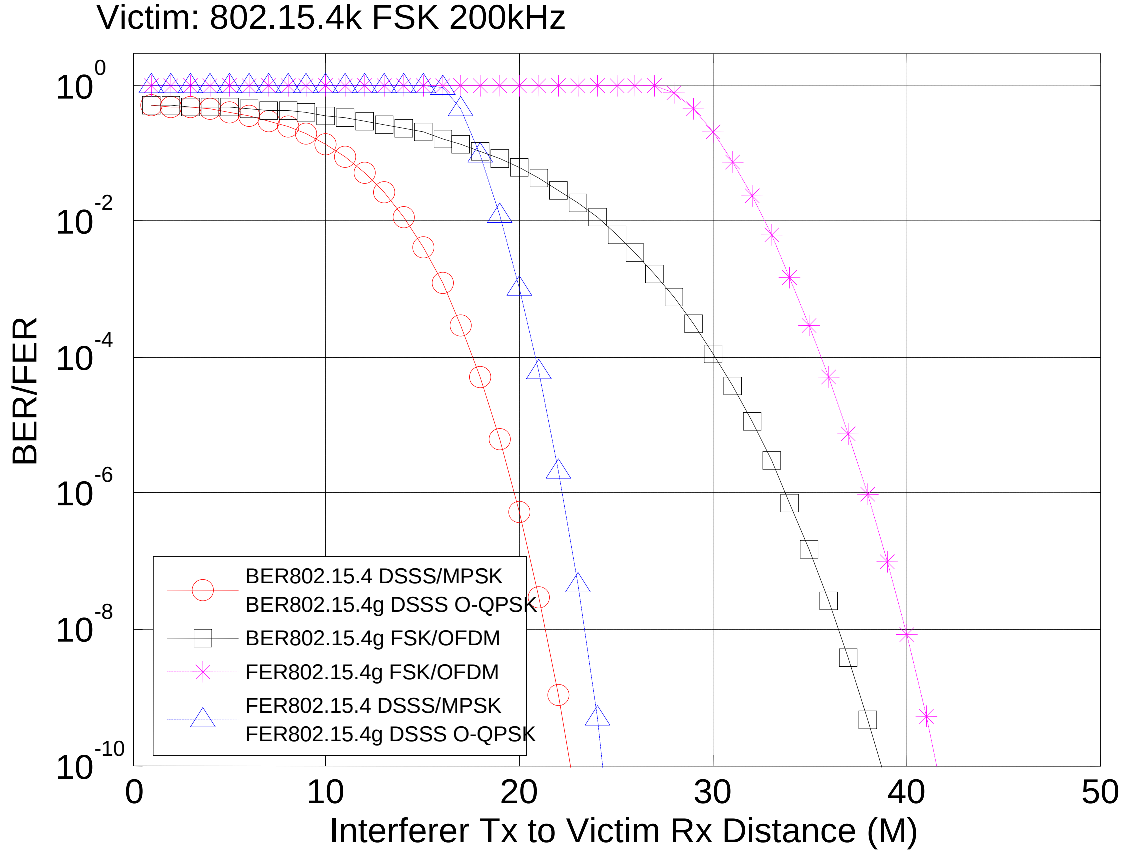

Figure 21: Victim BER/FER vs. Distance from Interferer Tx to 802.15.4k FSK Victim Rx (200 kHz)

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 802.15.4k interferer to the victim receiver.

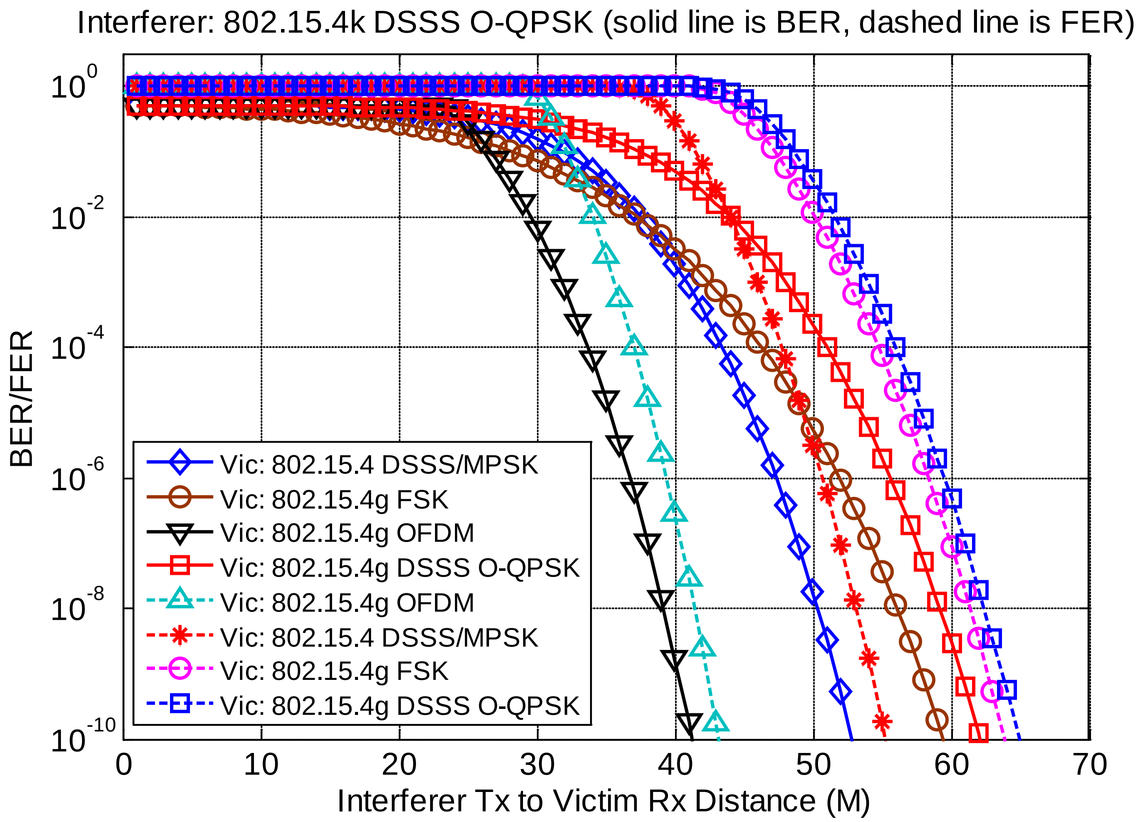

Figure 22: Victim BER/FER vs. Distance from Interferer Tx to 802.15.4 & 4g Victim Rx

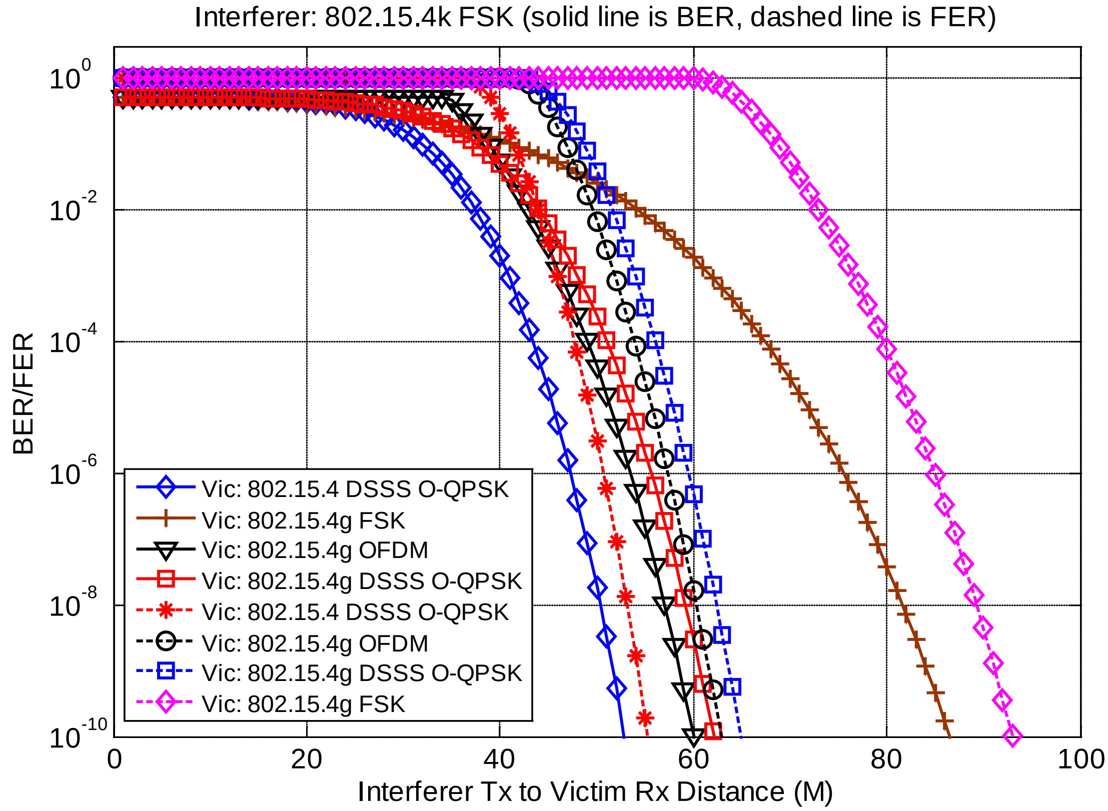

Figure 23: Victim BER/FER vs. Distance from Interferer Tx to 802.15.4 & 4g Victim Rx

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, 802.15.4k 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

System	PHY Spec	PHY Mode	Channel Bandwidth (kHz)	Transmit Power (dBm)	Receiver Sensitivity (dBm)	Average Frame Length (Octet)
802.15.4	DSSS	BPSK 300 kc/s, 20 kb/s	600	0	-85	22
	PSSS	ASK 400 kc/s, 250 kb/s	600	0	-85	22
	DSSS	O-QPSK 400 kc/s, 100 kb/s	600	0	-85	22
802.15.4g	MR-FSK	FSK 50 kb/s, h = 1.0	200	0	-91	250
	MR-OFDM	QPSK, 100 kb/s OFDM Option 4, MCS3	200	0	-103	20
	MR-O-QPSK	QPSK, 100 kc/s Rate Mode 3	600	0	-95	20

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.

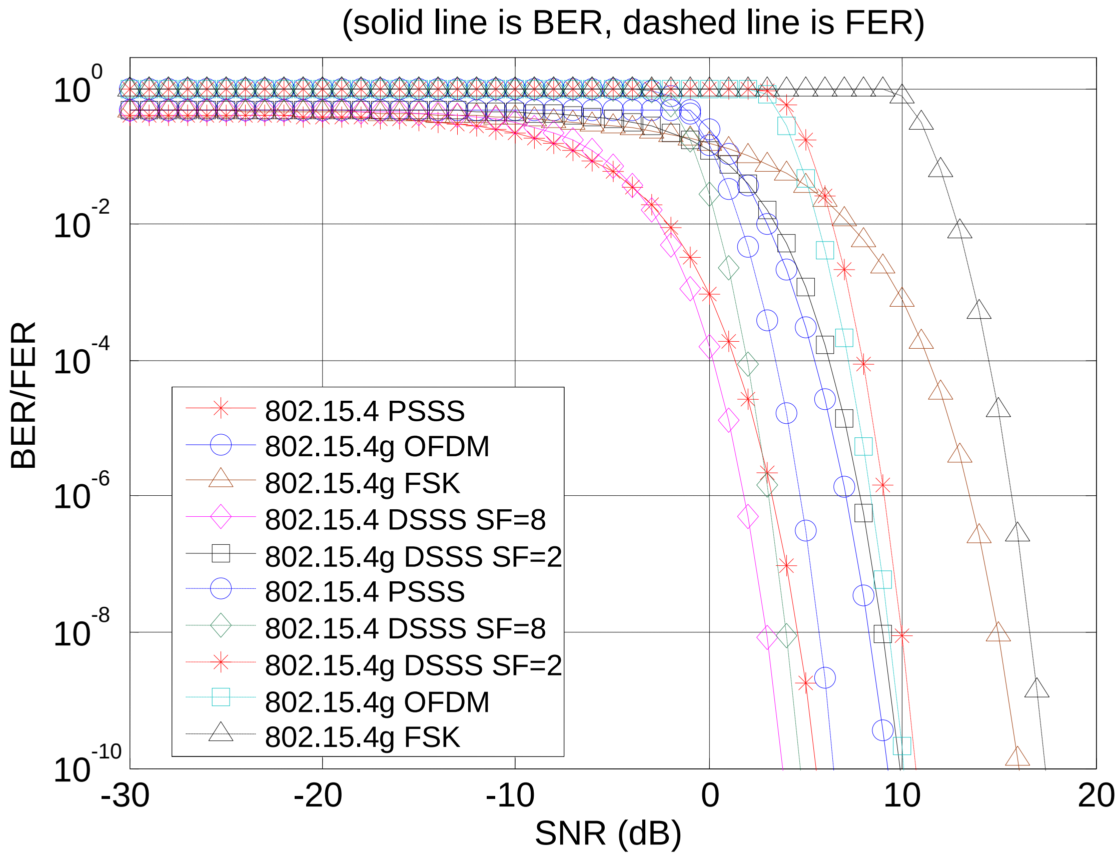

Figure 24: BER and FER vs. SNR for 802.15.4 & 4g Systems (863 - 870MHz band)

4.7.2 Coexistence Simulation Results

4.7.2.1 802.15.4k PHY Mode as Victim Receiver

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

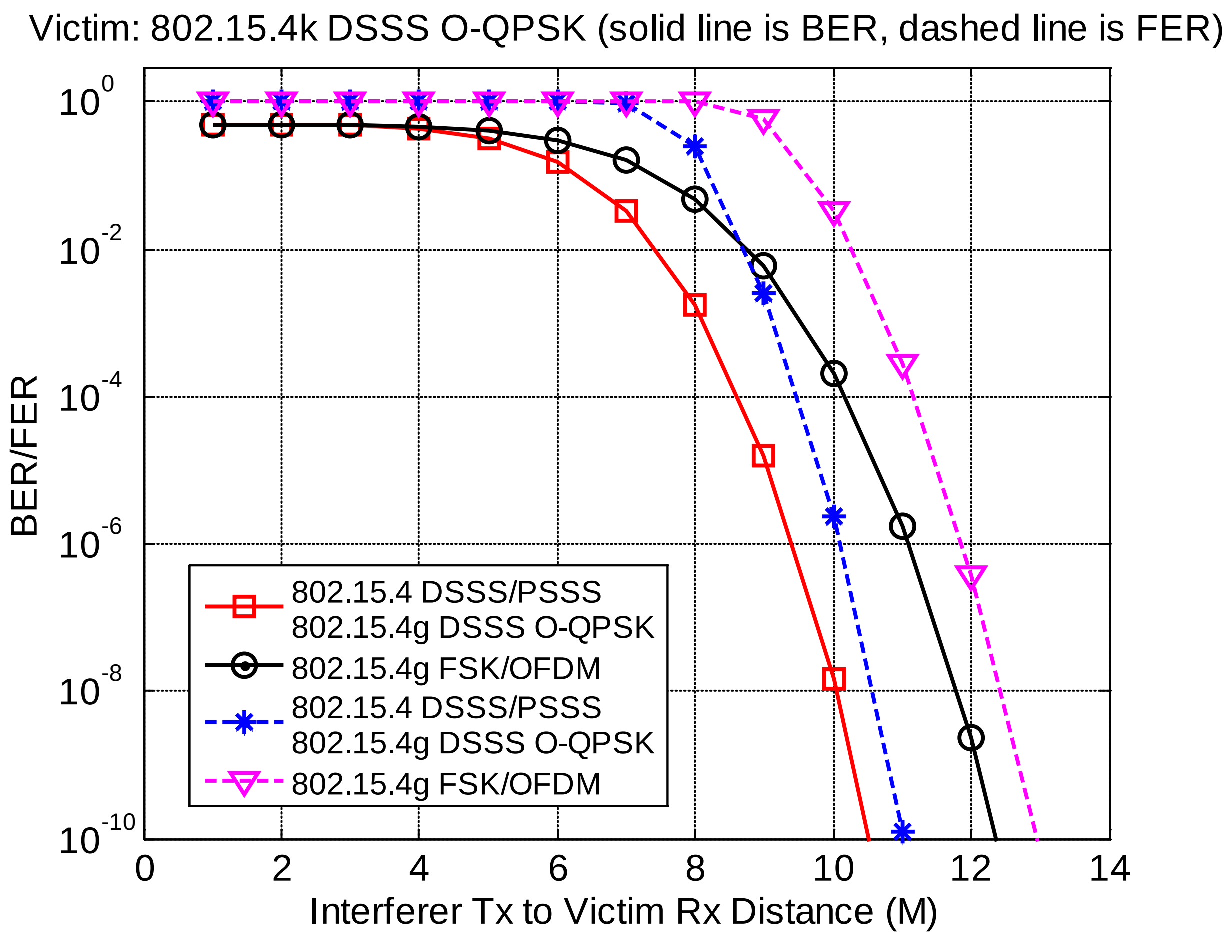

Figure 25: Victim BER/FER vs. Distance from Interferer Tx to 802.15.4k DSSS Victim Rx

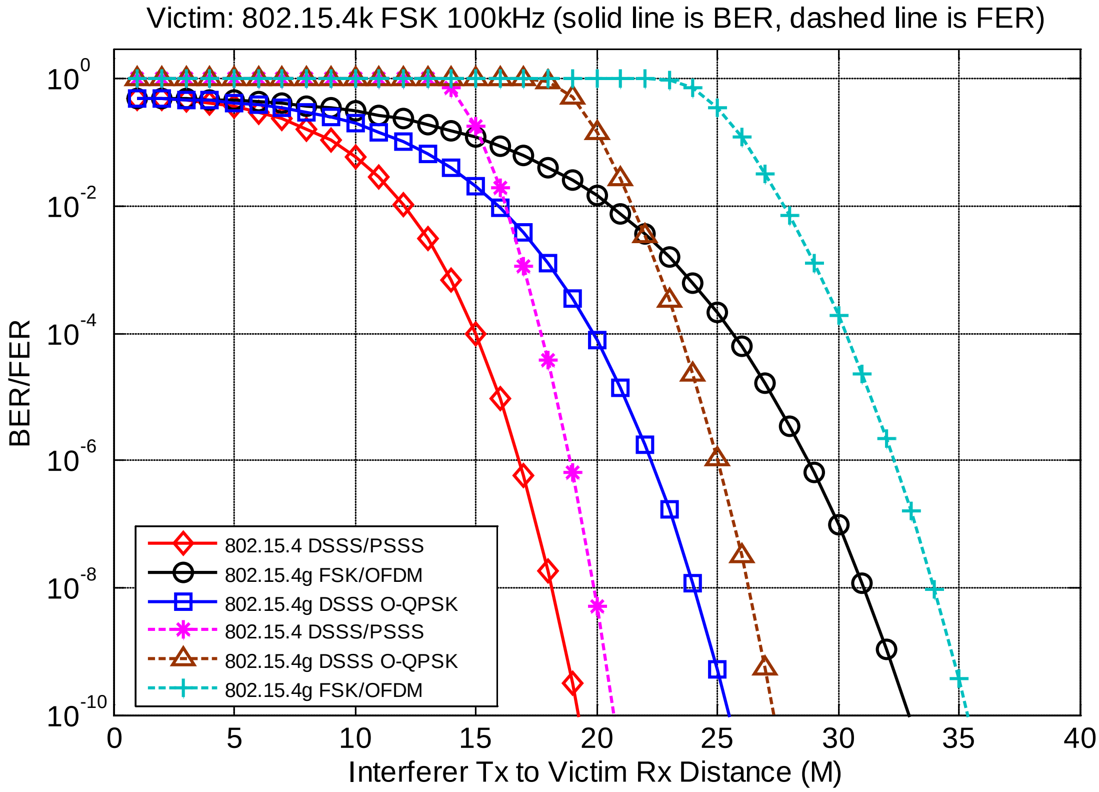

Figure 26: Victim BER/FER vs. Distance from Interferer Tx to 802.15.4k FSK Victim Rx (100 kHz)

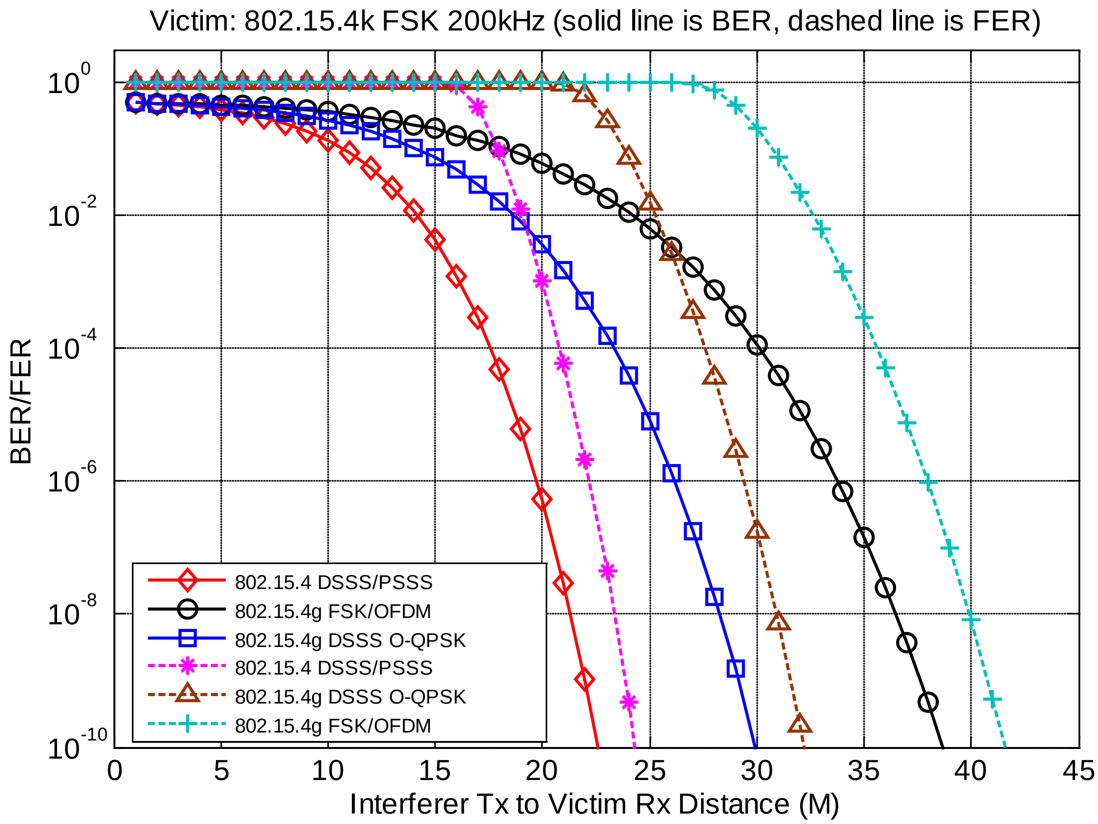

Figure 27: Victim BER/FER vs. Distance from Interferer Tx to 802.15.4k FSK Victim Rx (200 kHz)

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 802.15.4k interferer to the 802.15.4/4g victim receivers.

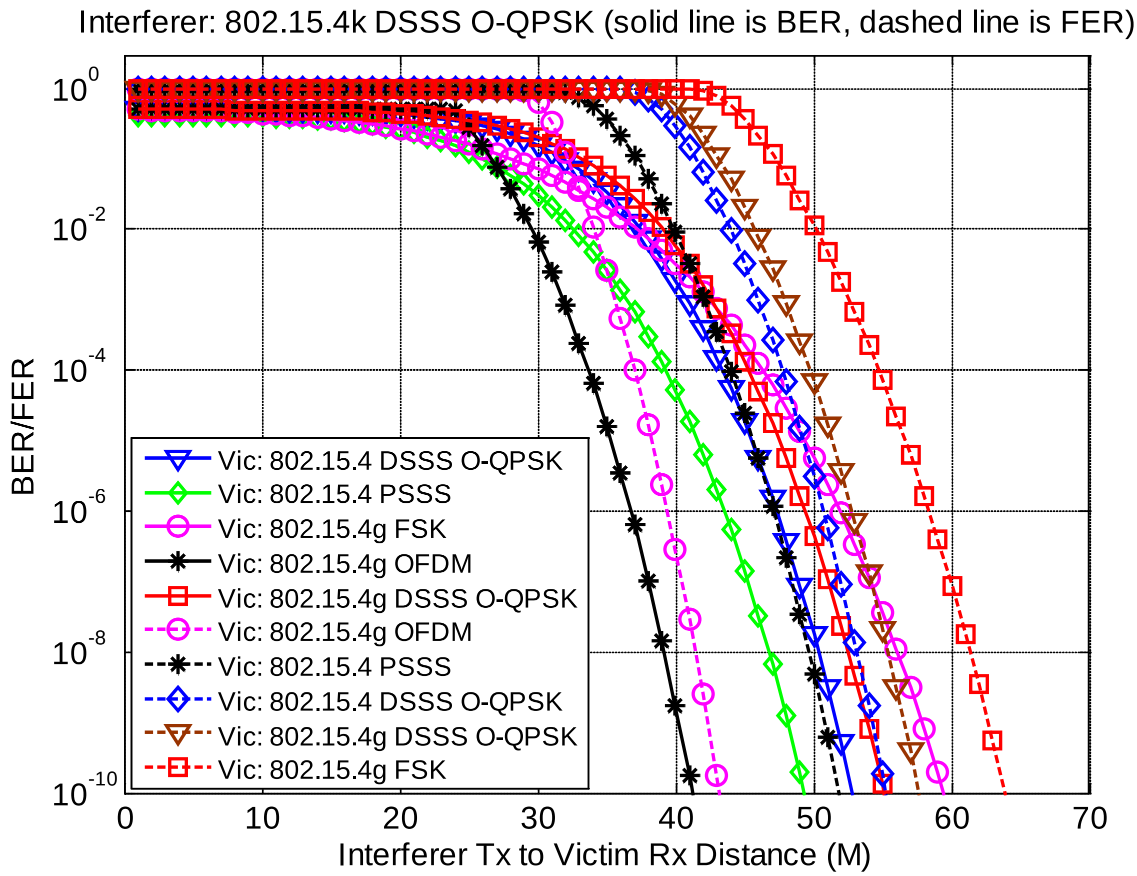

Figure 28: Victim BER/FER vs. Distance from Interferer Tx to 802.15.4 and 802.15.4 & 4g Victim Rx

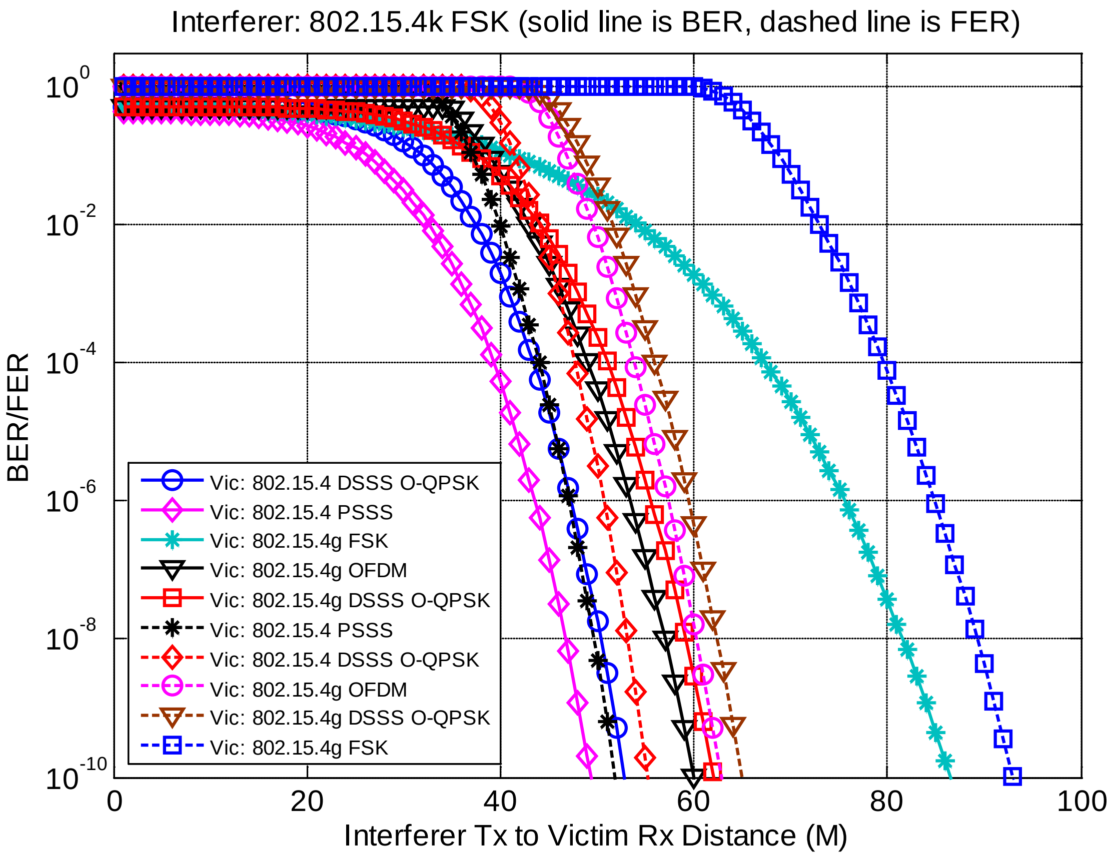

Figure 29: Victim BER/FER vs. Distance from Interferer Tx to 802.15.4 & 4g Victim Rx

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, 802.15.4k 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

System	PHY Spec	PHY Mode	Channel Bandwidth (kHz)	Transmit Power (dBm)	Receiver Sensitivity (dBm)	Average Frame Length (Octet)
802.15.4	DSSS	BPSK 600 kc/s, 40 kb/s	2000	0	-85	22
	PSSS	ASK 1600 kc/s, 250 kb/s	2000	0	-85	22
	DSSS	O-QPSK 1000 kc/s, 250 kb/s	2000	0	-85	22
802.15.4g	MR-FSK	FSK 50 kb/s, h = 1.0	200	0	-91	250
	MR-OFDM	QPSK, 100 kb/s OFDM Option 4, MCS3	200	0	-103	20
	MR-O-QPSK	QPSK, 1000 kc/s Rate Mode 3	2000	0	-90	20

Note: For the 920 – 928 MHz band the following MR-O-QPSK PHY parameters as shown in Table 16 are applied:

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

System	PHY Spec	PHY Mode	Channel Bandwidth (kHz)	Transmit Power (dBm)	Receiver Sensitivity (dBm)
802.15.4g	MR-O-QPSK	QPSK, 100 kc/s Rate Mode 3	200	0	-95

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.

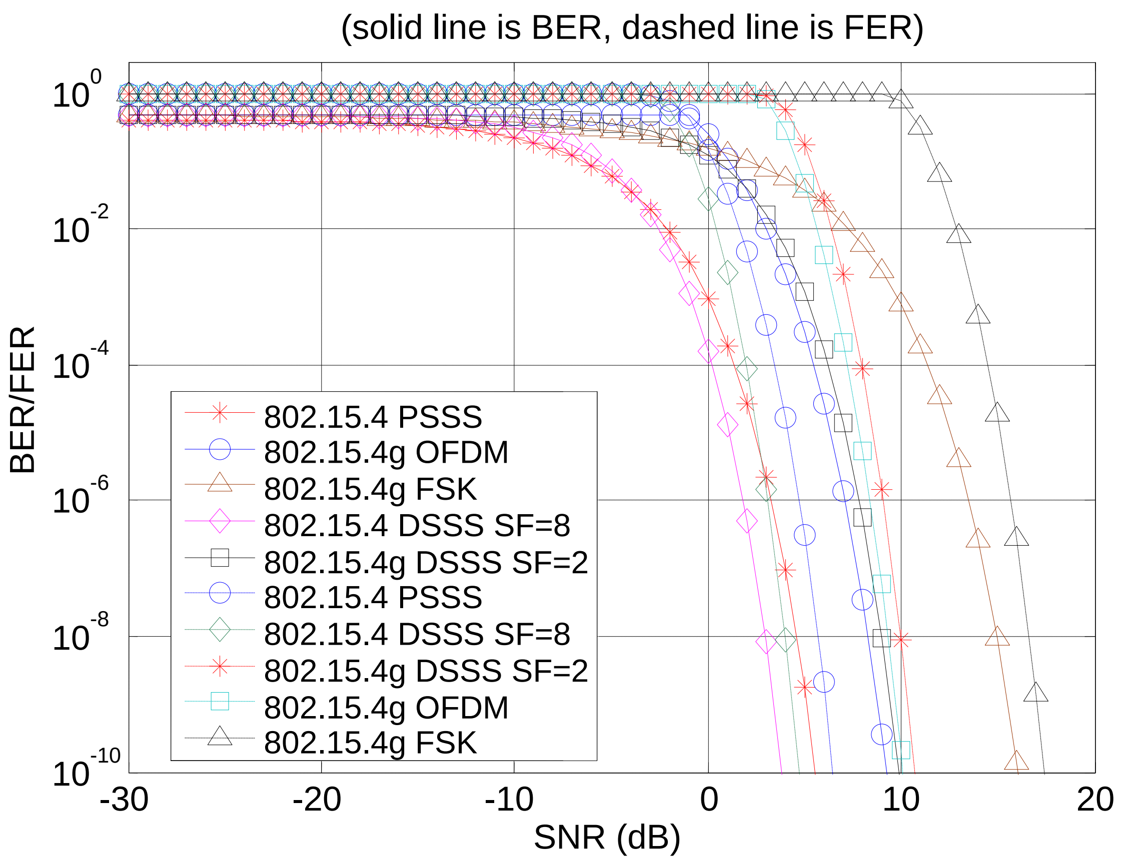

Figure 30: BER and FER vs. SINR for 802.15.4 & 4g Systems (902 - 928 MHz band)

4.8.2 Coexistence Simulation Results

4.8.2.1 802.15.4k PHY Mode as Victim Receiver

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

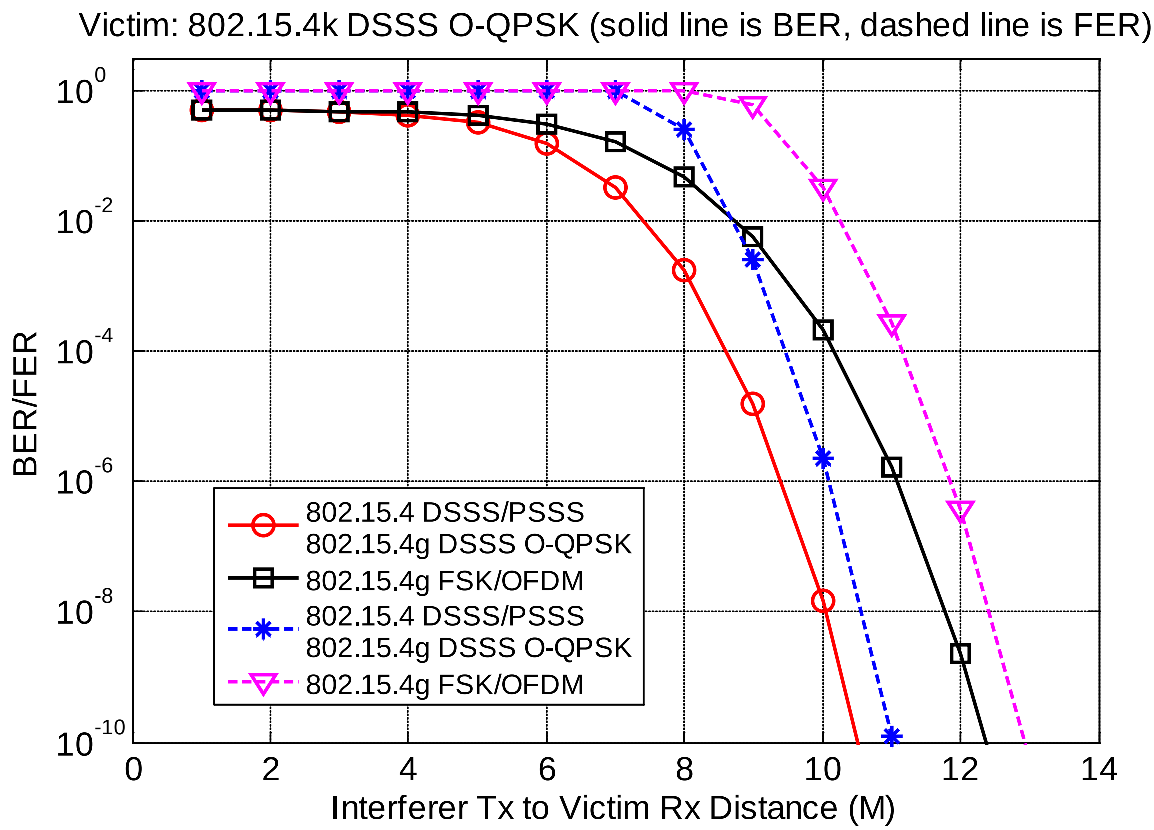

Figure 31: Victim BER/FER vs. Distance from Interferer Tx to 802.15.4k DSSS Victim Rx

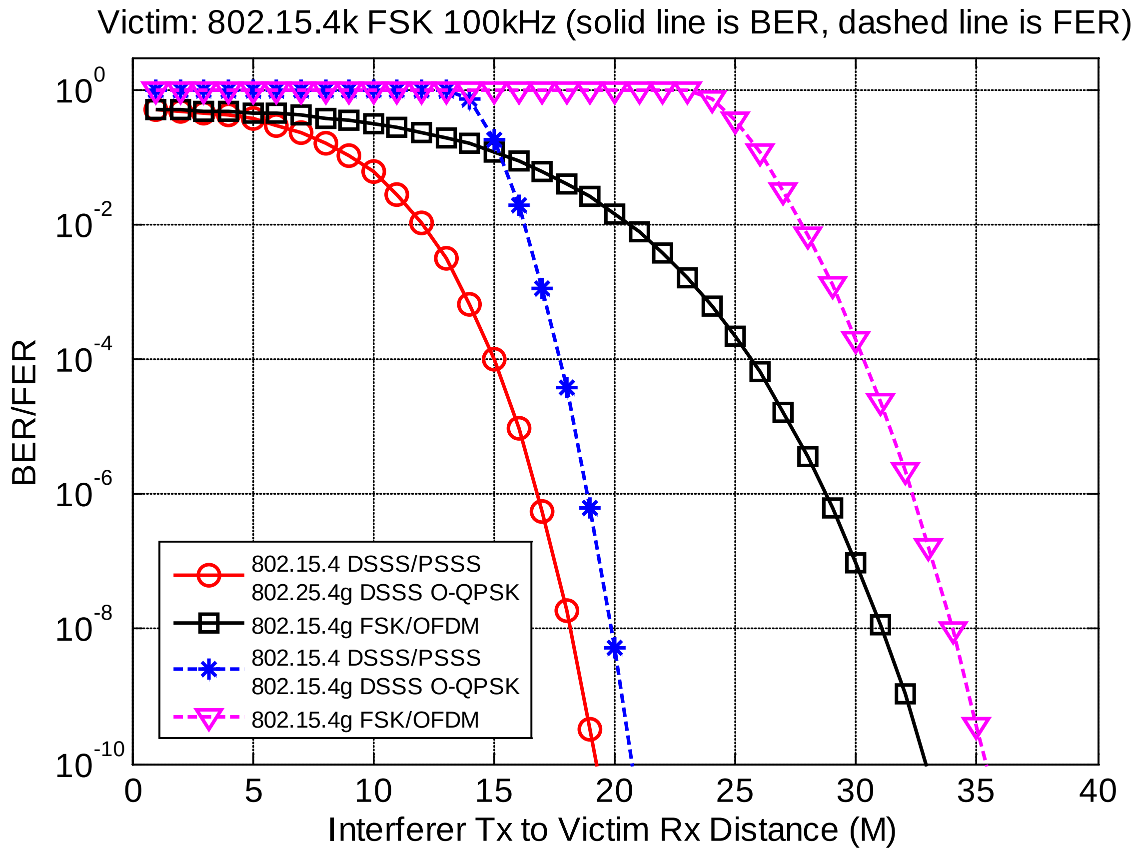

Figure 32: Victim BER/FER vs. Distance from Interferer Tx to 802.15.4k FSK Victim Rx (100 kHz)

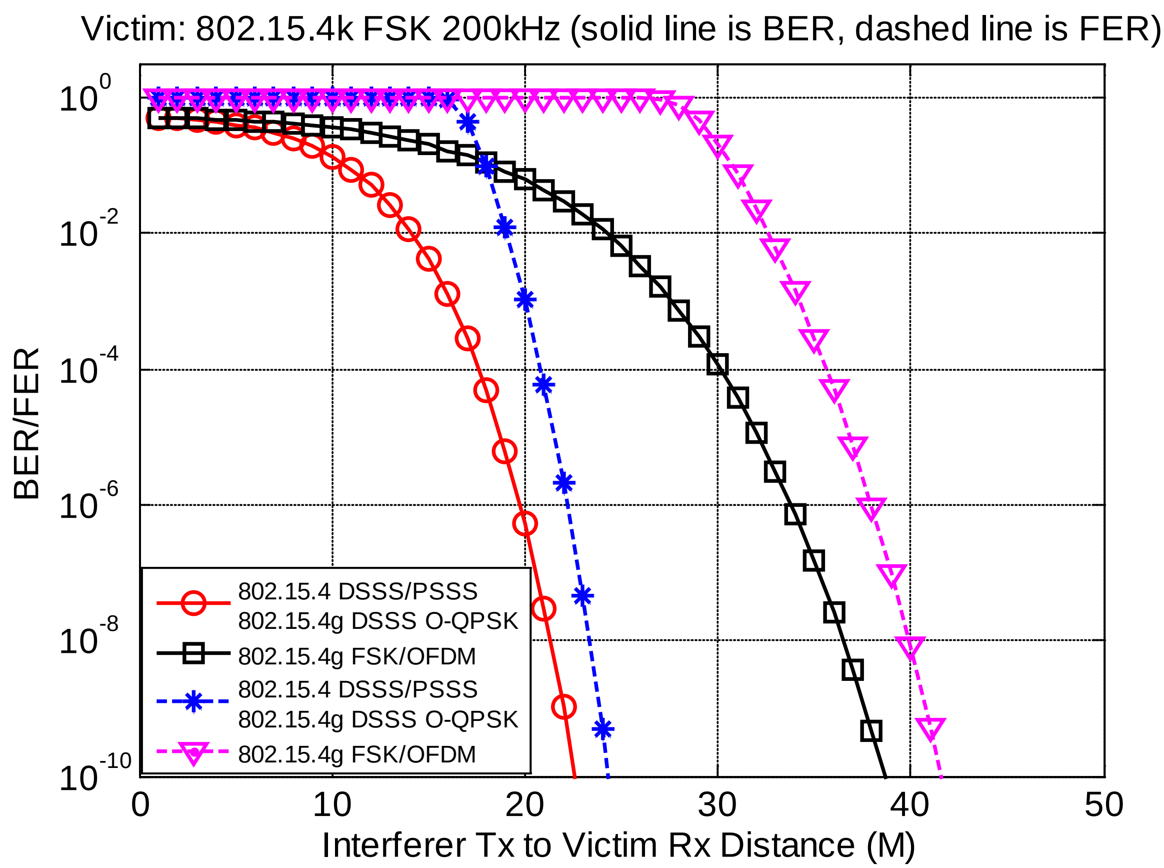

Figure 33: Victim BER/FER vs. Distance from Interferer Tx to 802.15.4k FSK Victim Rx (200 kHz)

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 802.15.4k interferer to the 802.15.4/4g victim receiver.

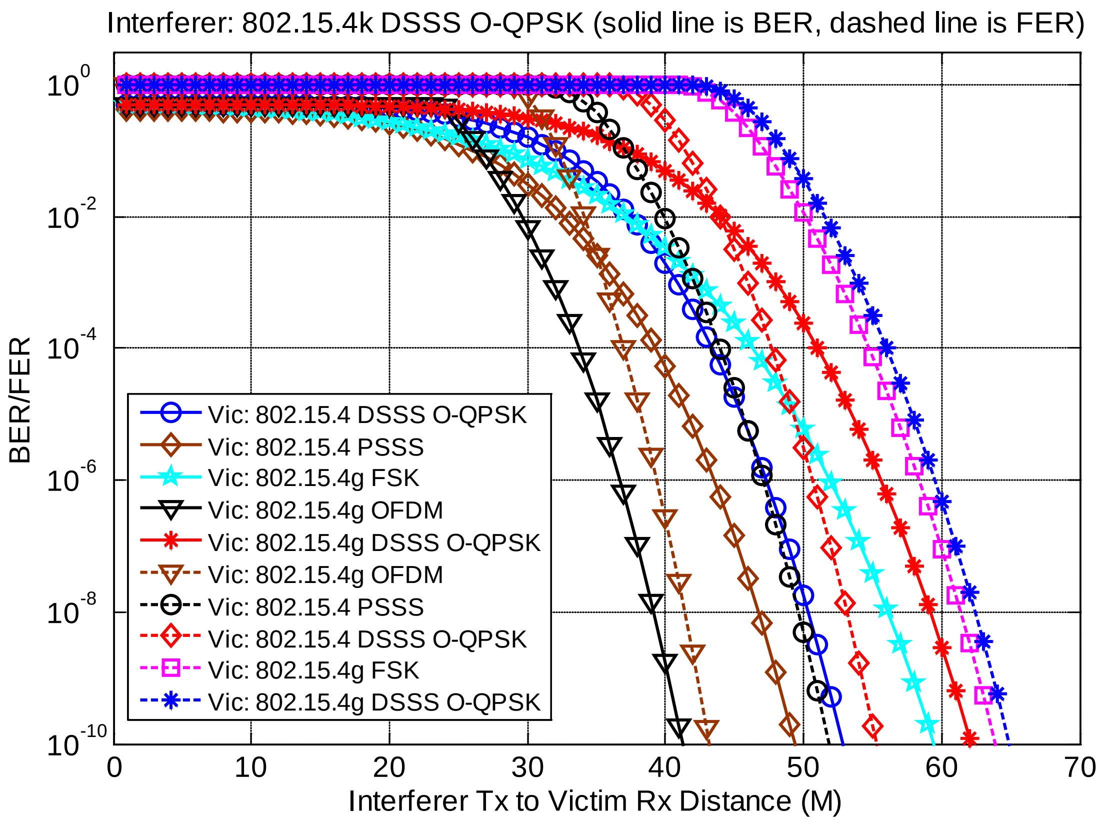

Figure 34: Victim BER/FER vs. Distance from Interferer Tx to 802.15.4 & 4g Victim Rx

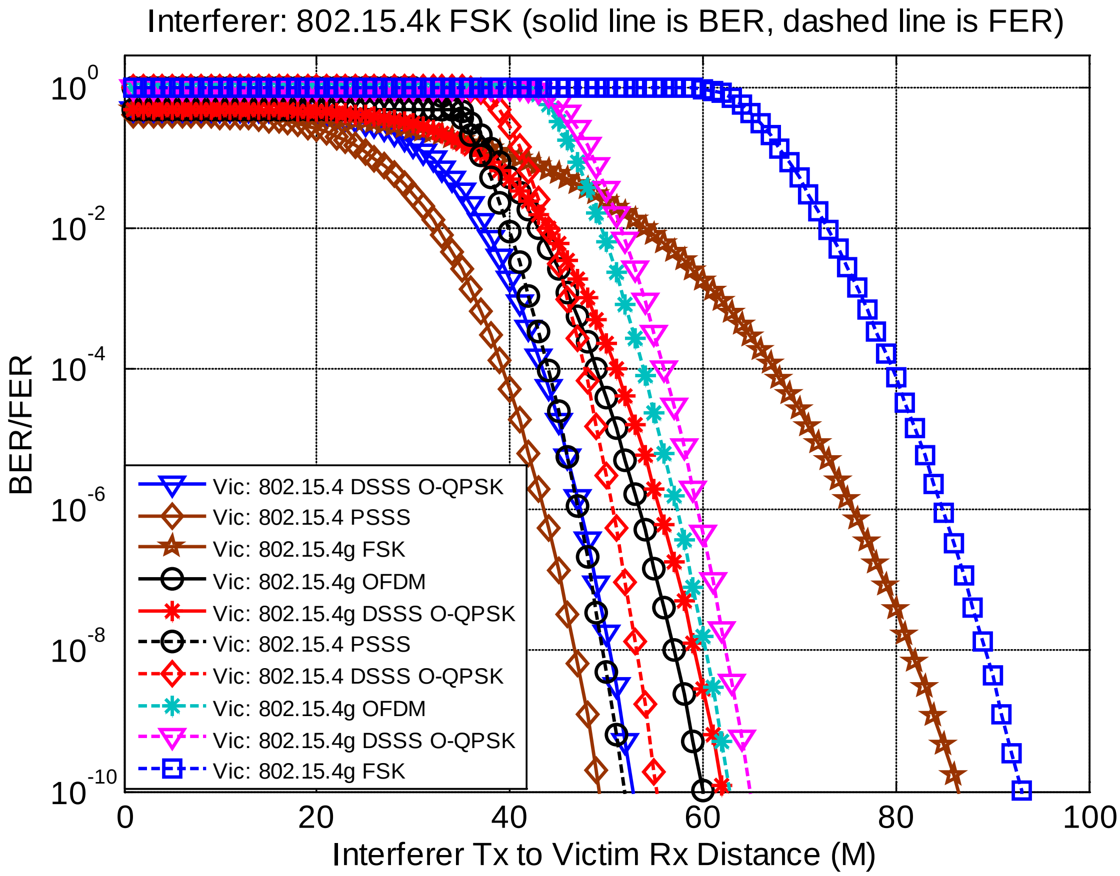

Figure 35: Victim BER/FER vs. Distance from Interferer Tx to 802.15.4 & 4g Victim Rx

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, 802.15.4k 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

System	PHY Spec	PHY Mode	Channel Bandwidth (MHz)	Transmit Power (dBm)	Receiver Sensitivity (dBm)	Average Frame Length (Octet)
802.11b	DSSS	CCK, 11 Mb/s	22	14	-76	1024
802.11g	OFDM	BPSK, 6 Mb/s	22	14	-88	1000
802.11n	OFDM	QPSK, 18 Mb/s	22	14	-83	4096
802.15.3	FHSS	GFSK, 1 Mb/s	1	0	-70	1024
802.15.4	SC	DQPSK, 22 Mb/s	15	8	-75	1024
802.15.4	DSSS	O-QPSK 2000 kc/s, 250 kb/s	2	0	-85	22
802.15.4f	MSK	MSK, 250 kb/s	0.58-	0	-	-
802.15.4g	MR-FSK	FSK 50 kb/s, h = 1.0	0.2	0	-91	250
	MR-OFDM	QPSK, 100 kb/s OFDM Option 4, MCS3	0.2	0	-103	20
	MR-O-QPSK	QPSK, 2000 kc/s Rate Mode 3	5	0	-90	20

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.

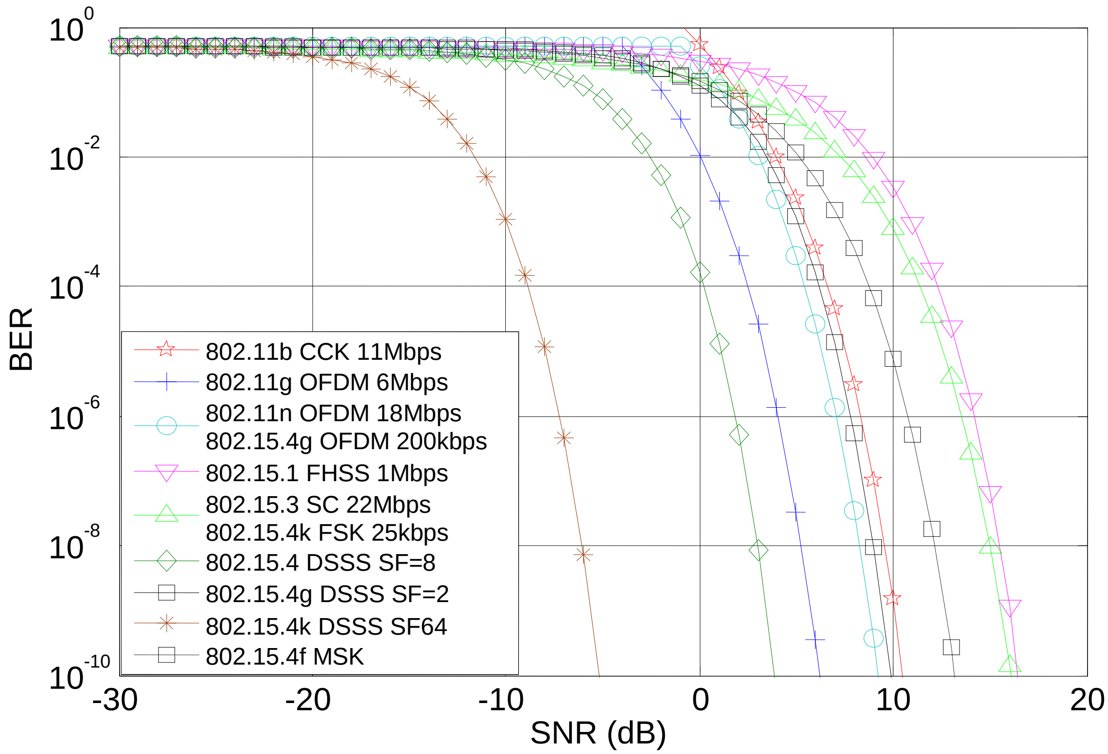

Figure 36: BER vs. SINR for 802.11 & 802.15 Systems (2400 – 2483.5MHz band)

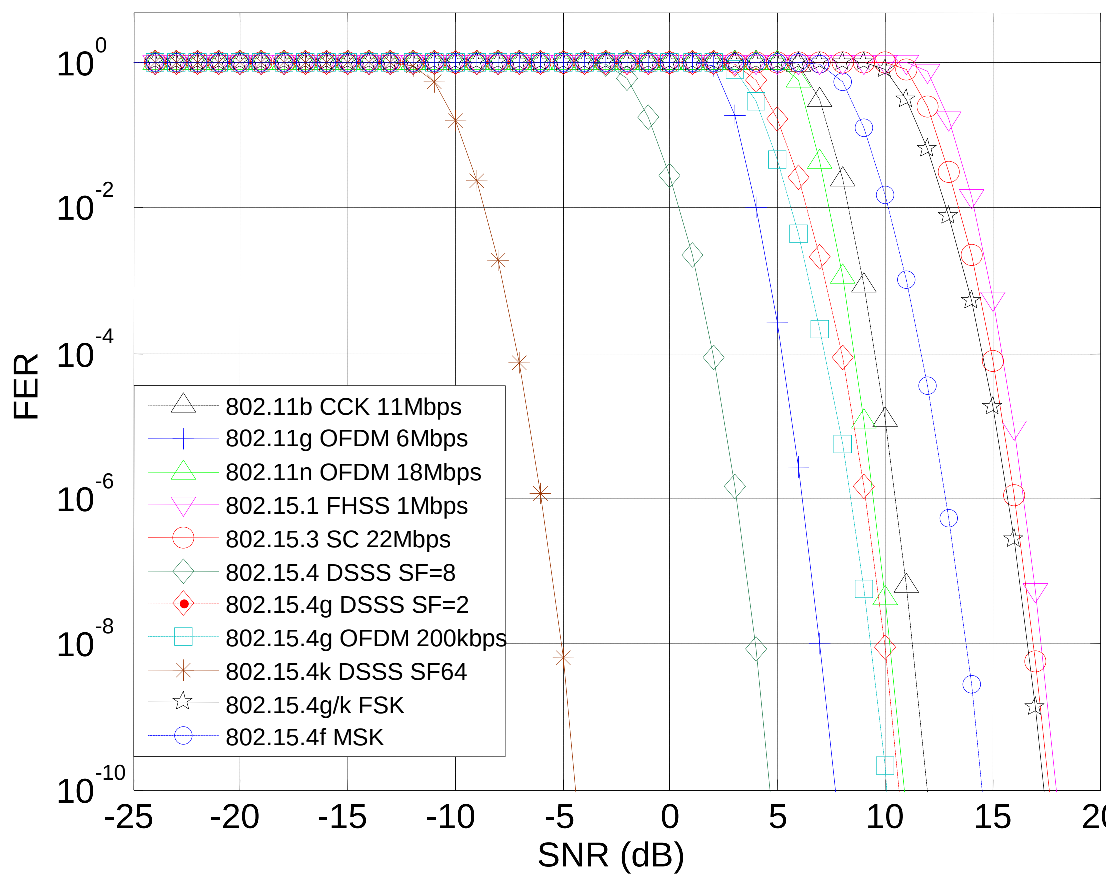

Figure 37: FER vs. SINR for 802.11 & 802.15 Systems (2400 – 2483.5MHz band)

4.9.2 Coexistence Simulation Results

4.9.2.1 802.15.4k PHY Mode as Victim Receiver

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

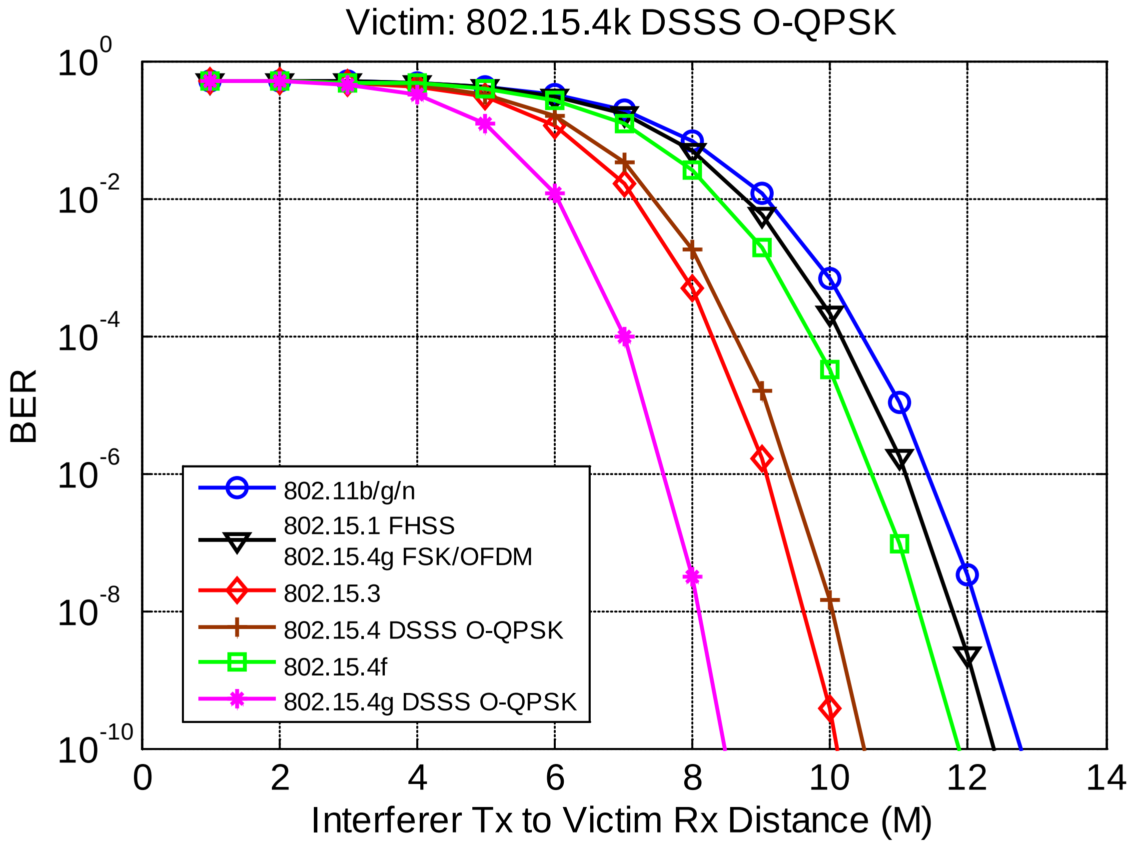

Figure 38: Victim BER vs. Distance from Interferer Tx to 802.15.4k DSSS Victim Rx

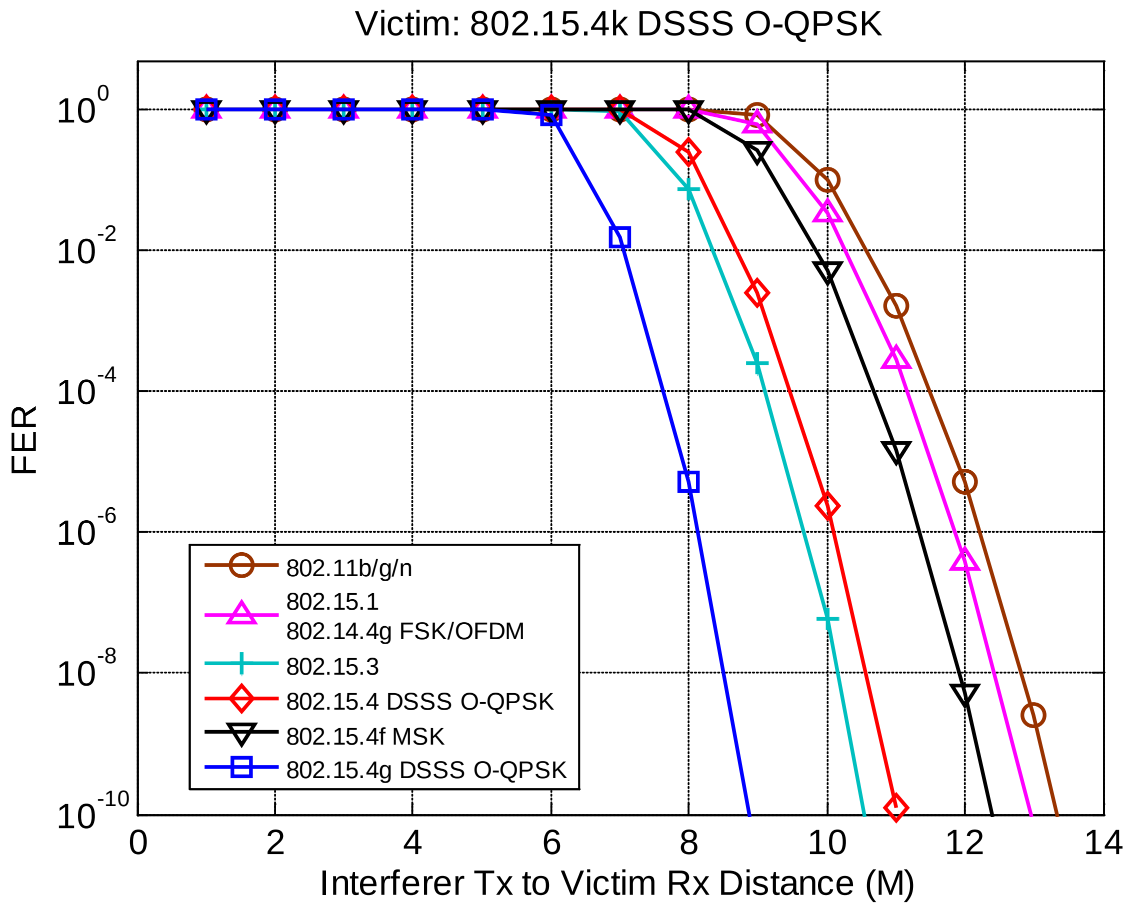

Figure 39: Victim FER vs. Distance from Interferer Tx to 802.15.4k DSSS Victim Rx

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 802.15.4k interferer to the 802.11 victim receiver at different interferer's transmitting power levels.

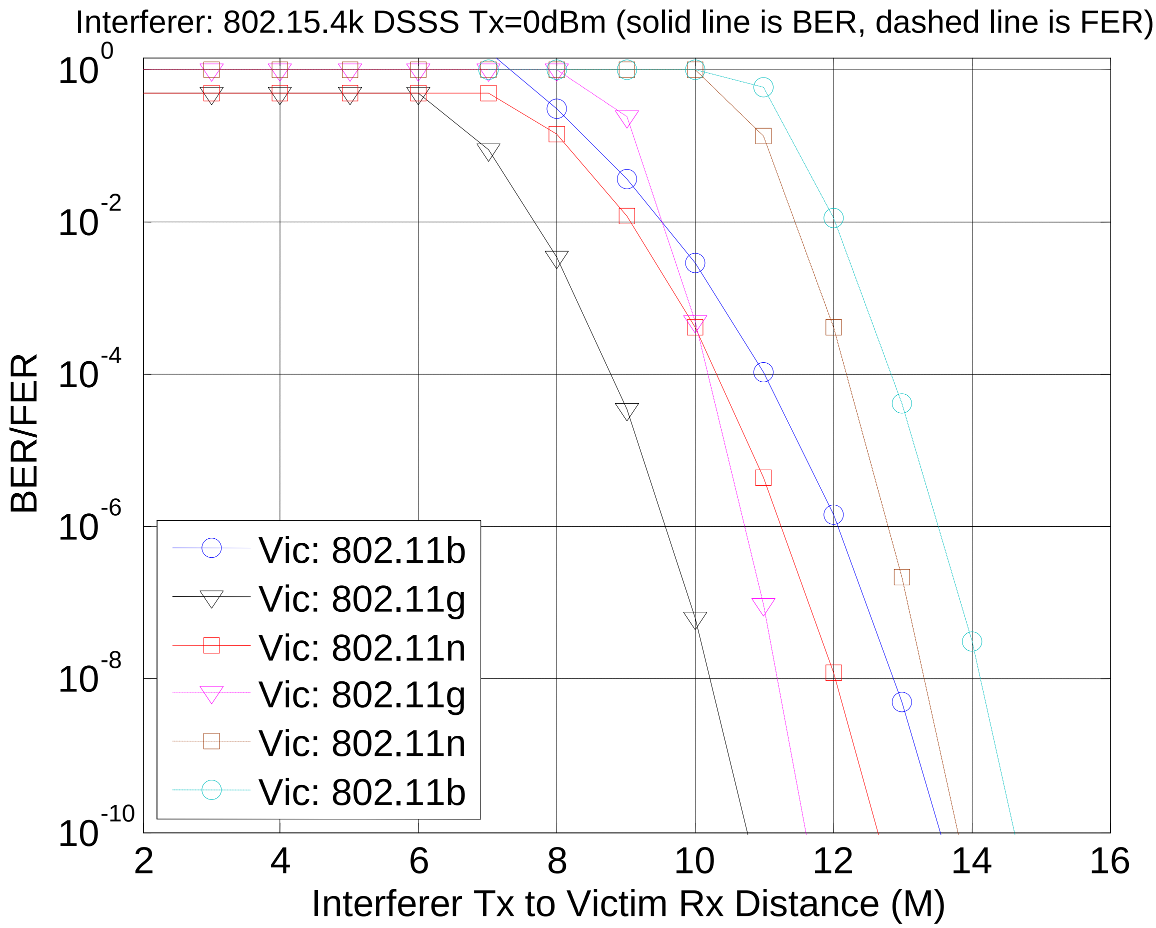

Figure 40: Victim BER/FER vs. Distance from Interferer Tx (0dBm) to 802.11 Victim Rx

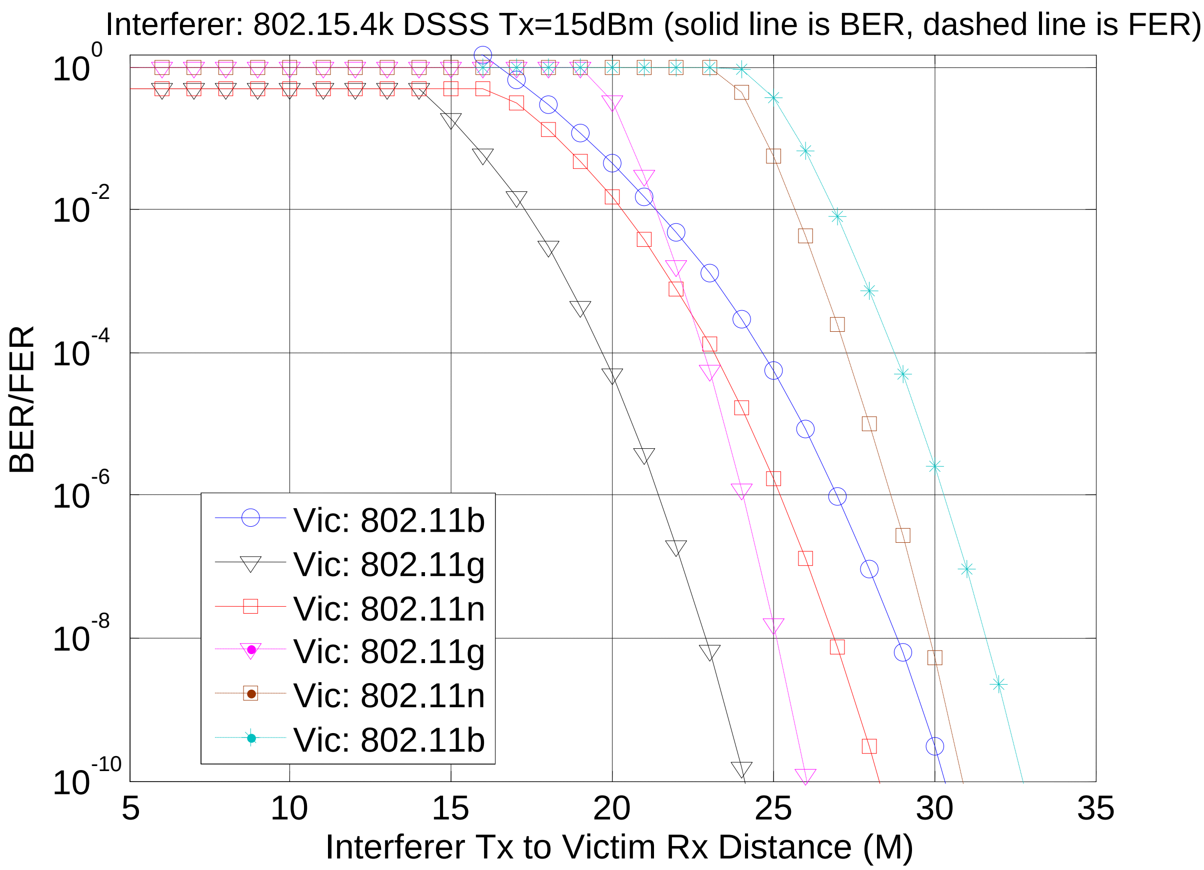

Figure 41: Victim BER/FER vs. Distance from Interferer Tx (15dBm) to 802. 11 Victim Rx

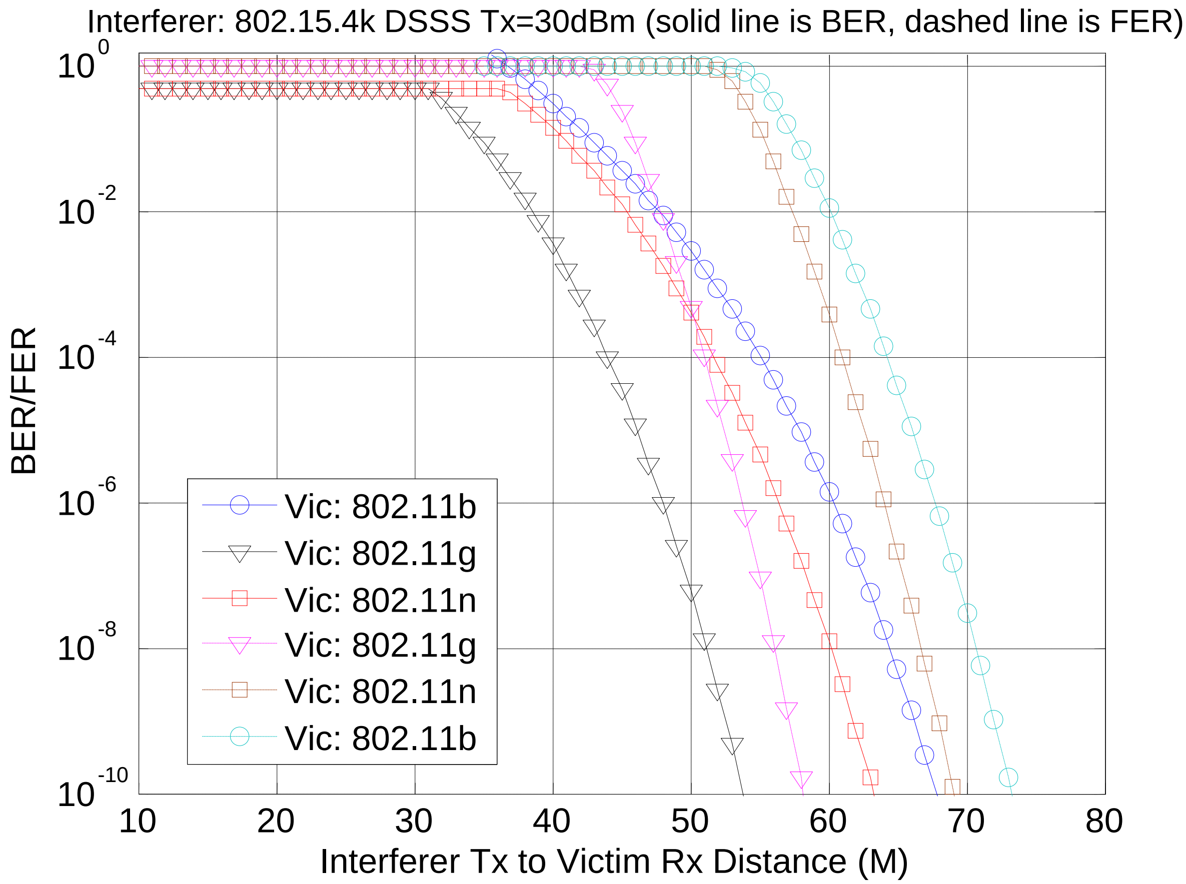

Figure 42: Victim BER/FER vs. Distance from Interferer Tx (30dBm) to 802. 11 Victim Rx

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 802.15.4k interferer to the 802.15 victim receivers at different interferer’s transmitting power levels.

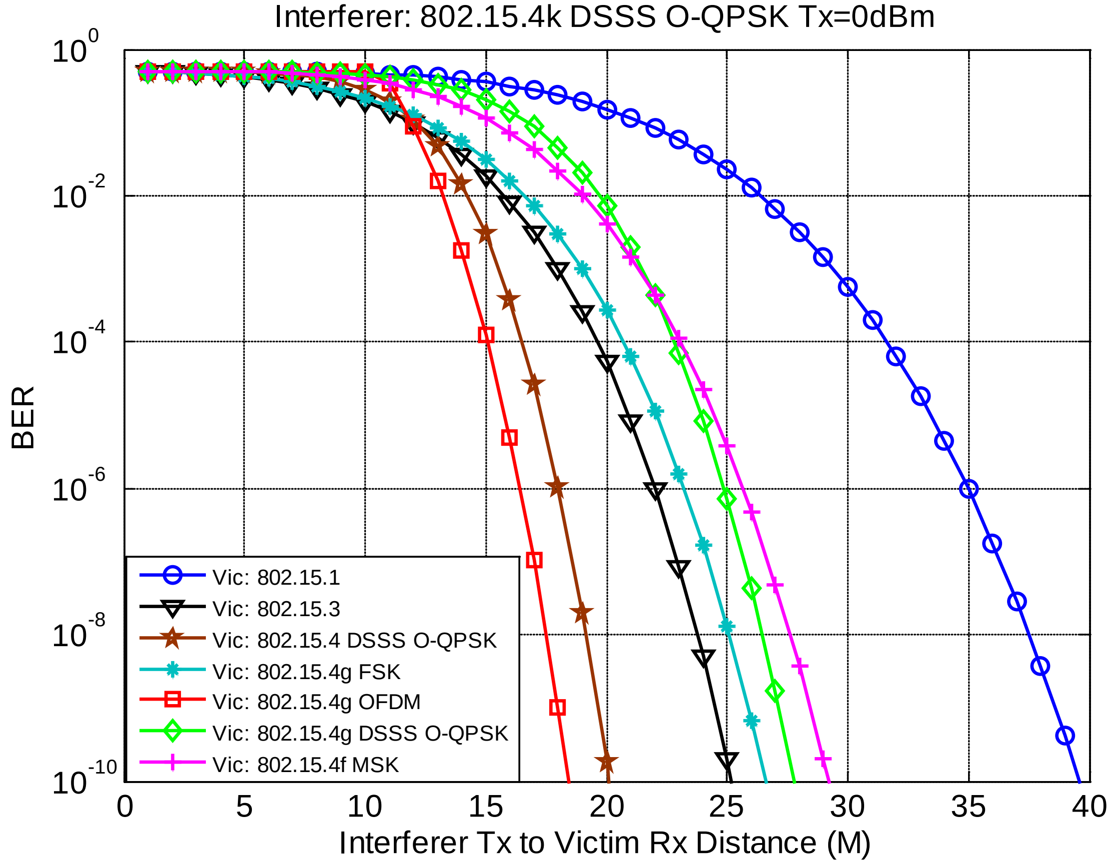

Figure 43: Victim BER vs. Distance from Interferer Tx (0dBm) to 802.15 Victim Rx

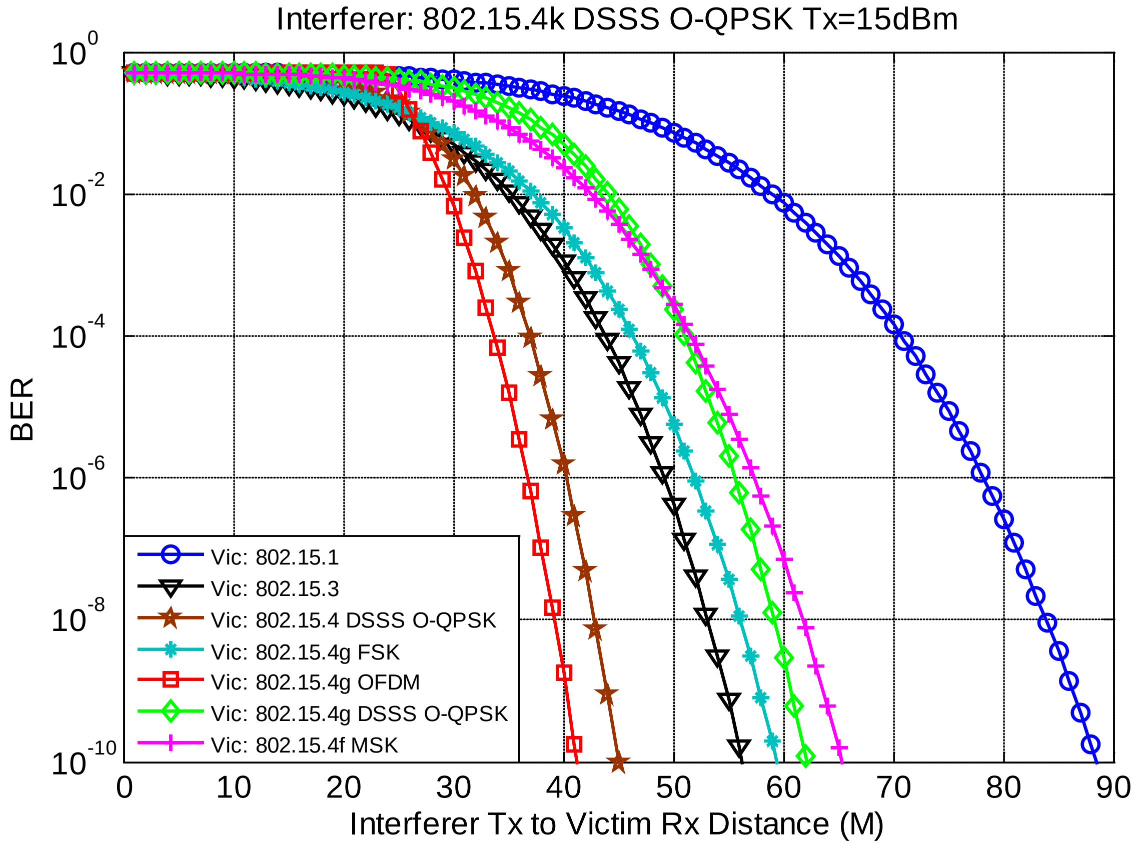

Figure 44: Victim BER vs. Distance from Interferer Tx (15dBm) to 802.15 Victim Rx

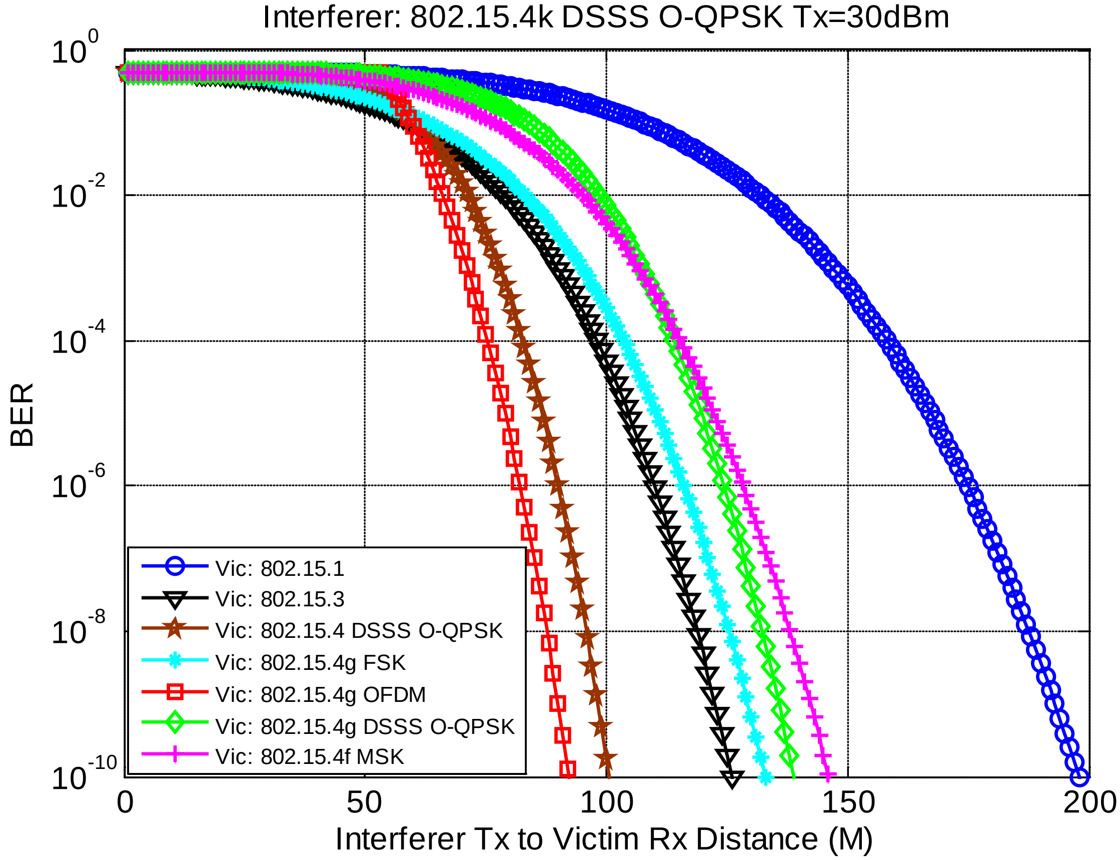

Figure 45: Victim BER vs. Distance from Interferer Tx (30dm) to 802.15 Victim Rx

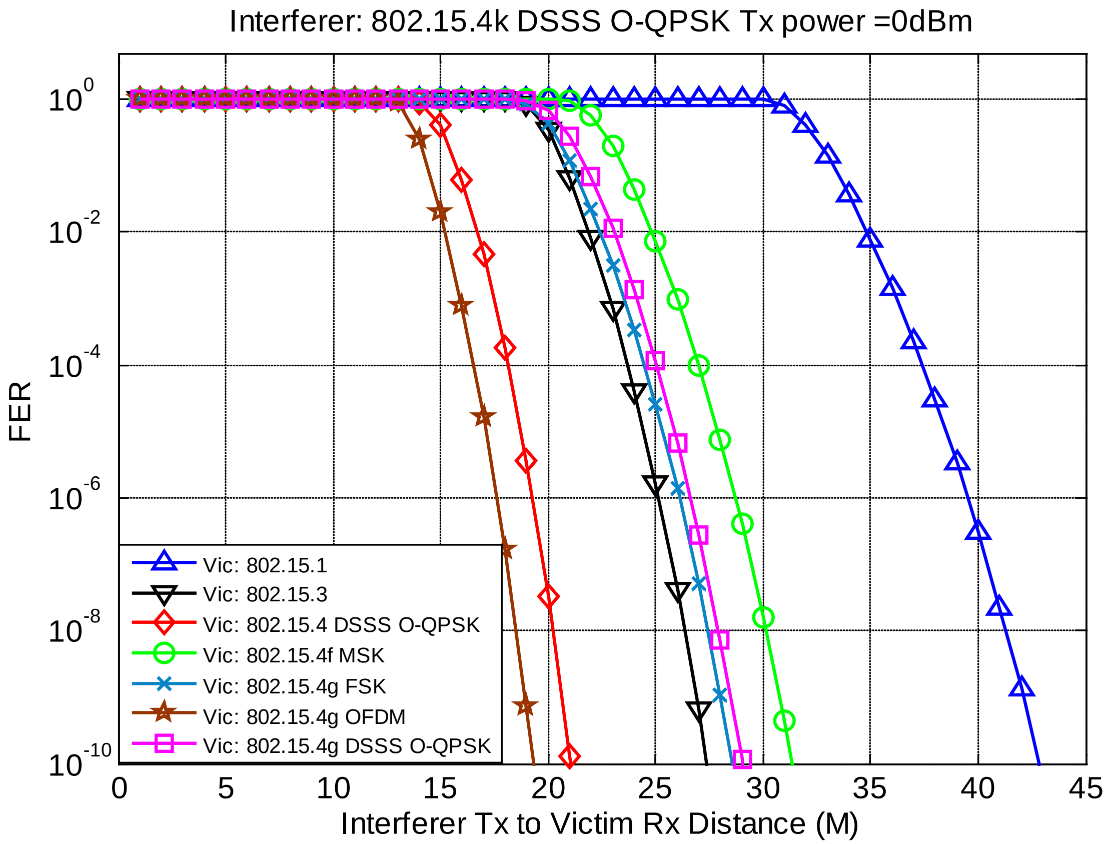

Figure 46: Victim FER vs. Distance from Interferer Tx (0dBm) to 802.15 Victim Rx

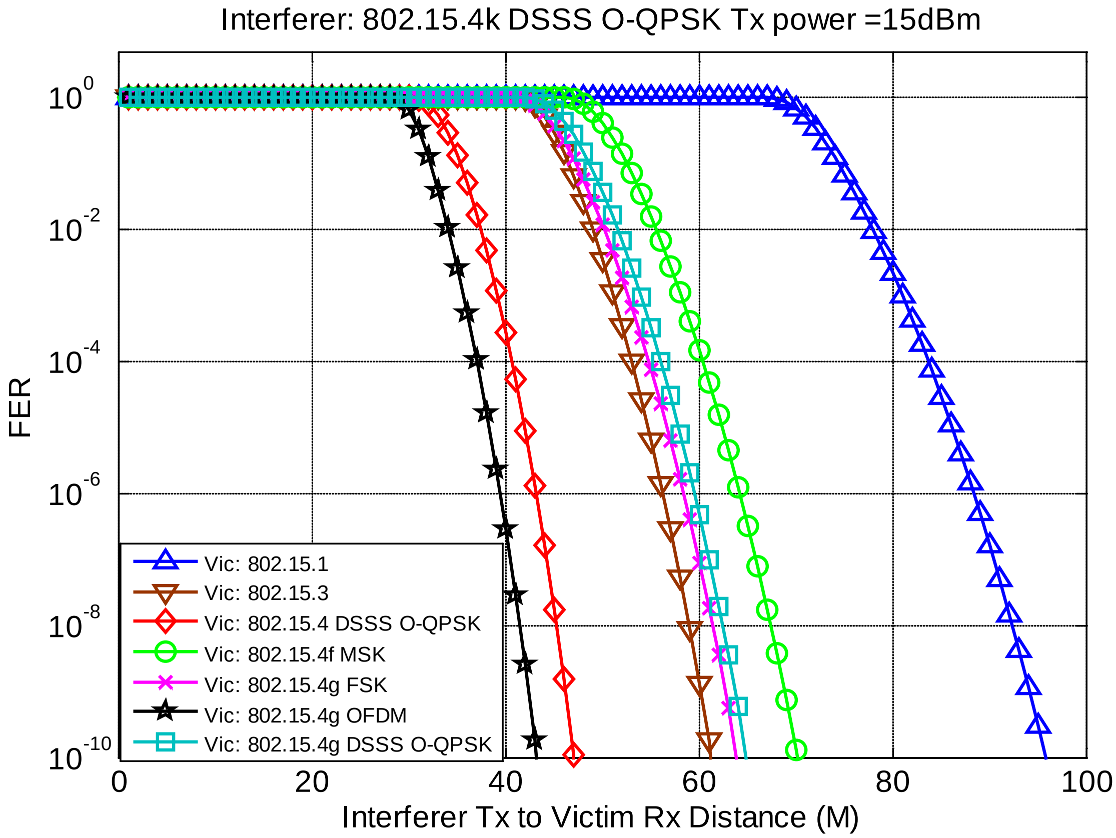

Figure 47: Victim FER vs. Distance from Interferer Tx (15dBm) to 802.15 Victim Rx

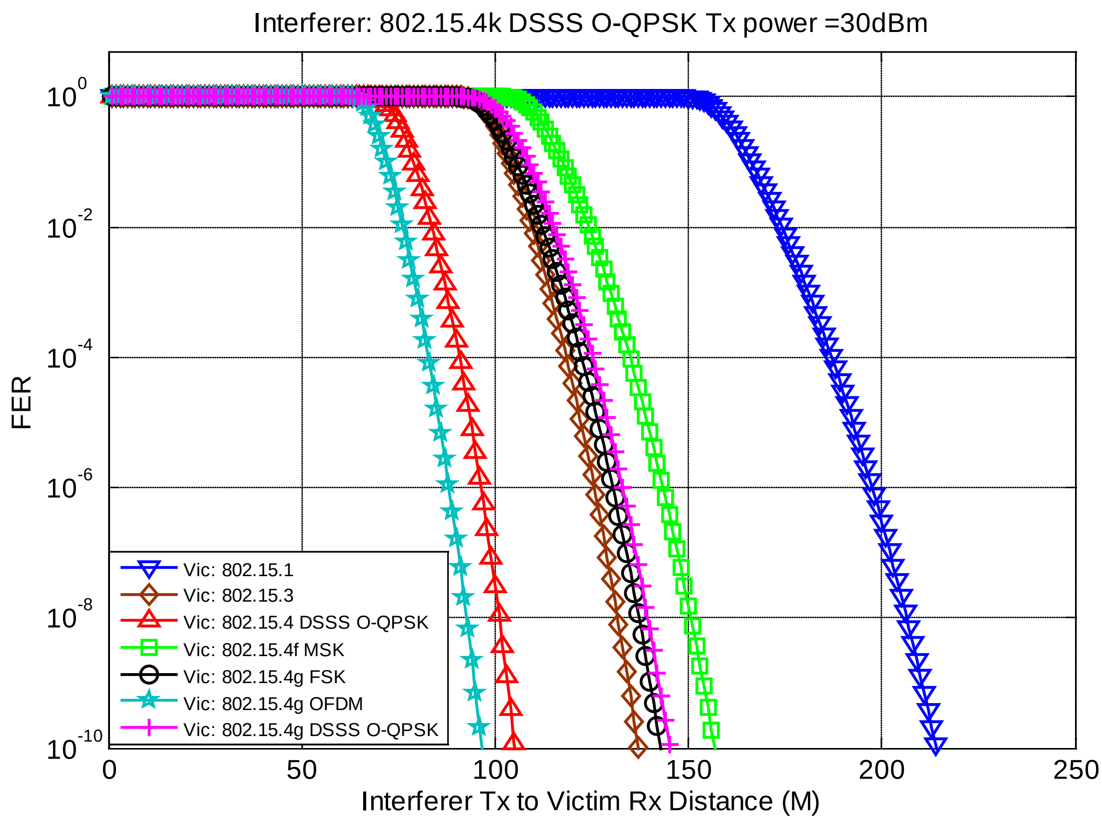

Figure 48: Victim FER vs. Distance from Interferer Tx (30dBm) to 802.15 Victim Rx

5 Interference Avoidance and Mitigation Techniques

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

6 Conclusions

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

As an interferer, either 802.15.4k FSK or 802.15.4k 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 802.15.4k system is designed to operate at a high transmitting power level.