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UWB and WLAN Coexistence: a Comparison of Interference Reduction Techniques

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UWB and WLAN Coexistence:
a Comparison of Interference Reduction Techniques

by

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DEDICATION

To my dear parents,

Dr. Vijay Kajale & Mrs. Kavita Kajale

and my loving fiancée

Vandana

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I would like to express my deepest gratitude to my major professor, Dr. Ravi Sankar for his guidance and incredible patience. His valuable insights and advice have helped me throughout my research. I am ever thankful to Dr. Wilfrido Moreno for his encouragement and support. I would like to extend my appreciation to Dr. Huseyin Arslan for his comments and advice. Furthermore, I would like to thank my parents Dr. Vijay Kajale and Mrs. Kavita Kajale, my brother Mr. Vikram Kajale, and my fiancée Vandana for their inspiration and love.

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UWB AND WLAN COEXISTENCE:
A COMPARISON OF INTERFERENCE REDUCTION TECHNIQUES

Nikhil Vijay Kajale

ABSTRACT

Ultra Wideband (UWB) is an emerging technology for use in the indoor wireless personal area networks and ad hoc networks. The more common form of UWB which uses sub-nanosecond pulses without any form of carrier signal is considered in this research. UWB signals have a large bandwidth with allocated frequency spectrum from 3.1 GHz to 10.6 GHz and maximum power restricted to -41dBm/MHz. The IEEE 802.11a is a popular standard for high data rate wireless local area networks (WLANs). The operating frequency of the IEEE 802.11a WLAN is 5 GHz which is right inside the allocated UWB frequency spectrum.

One of the main obstacles facing the implementation of UWB devices is the challenge of reducing interference caused by UWB to other systems and vice versa. The potential operating areas/frequencies of the IEEE 802.11a WLAN and UWB systems overlap and therefore the problem of UWB interference to the IEEE 802.11a WLANs and vice versa becomes significant.

In this research we have focused on studying the effect of UWB interference on IEEE 802.11a WLANs. The different UWB parameters that affect the interference caused by UWB to IEEE 802.11a WLAN have been considered for determining their effect on the performance of the IEEE 802.11a WLAN. The effect of UWB multipath on the performance of the IEEE 802.11a WLAN has been observed. The UWB parameters have also been compared based on their effect on the performance of the IEEE 802.11a system in the

presence of UWB multipath. Additionally, two different interference mitigation techniques that reduce UWB interference to the IEEE 802.11a WLANs have been studied. These techniques have also been compared with respect to their effect on the performance of the IEEE 802.11a WLAN in the presence and absence of UWB multipath.

CHAPTER 1

INTRODUCTION

1.1 Ultra Wideband Technology

Ultra Wideband (UWB), due to its large bandwidth, is capable of supporting high data rate applications. The UWB signals are very low power signals as the Federal Communications Commission (FCC) has imposed a maximum power restriction of -41dbm/MHz. The UWB transceiver can consist of mostly digital signal processing (DSP) components and can therefore be relatively small and light as compared to Radio Frequency (RF) devices.

These characteristics of UWB signals make them a very good choice for indoor wireless high data rate applications. The applications of UWB devices are widespread including both PC based and consumer oriented devices. Potentially a large number of UWB devices may operate in close proximity of an indoor wireless application such as a WLAN. The UWB signal is a very low power signal and therefore the power of any single UWB device can be compared to that of a noise floor. But when a number of such devices operate simultaneously then the interference level could rise significantly above the level of the noise floor.

1.2 IEEE 802.11a Wireless LAN

WLAN is a technology used to connect devices located within a local area such as an office space or a lab. The IEEE 802.11a is a popularly used standard for high data rate WLANs. The operating frequency of the IEEE 802.11a WLAN is 5 GHz. Another standard for the WLANs is the IEEE 802.11b which operates at the 2.4 GHz band. For long range applications, IEEE 802.11b is preferred over IEEE 802.11a. If a large data rate is needed such as in video or large file transmissions then IEEE 802.11a system is preferred. The potential operating area for IEEE 802.11a is for short range high data rate applications. These could be computer based or consumer oriented applications.

1.3 Motivation

There is a possibility that we could see a number of UWB devices in PCs and/or other portable devices in the market in a few years. We have seen that UWB devices are ideal for wireless personal area networks (WPANs) which could be often located within larger wireless local area networks (WLANs). In this scenario we have to consider the interference that UWB signals would cause to other systems that are located in the frequency band from 3.1 to 10.6 GHz especially the IEEE 802.11a WLANs. There is a need to compare the throughput and BER performances of the IEEE 802.11a WLAN system by using different UWB parameters. The throughput and BER performances of an IEEE 802.11a WLAN need to be monitored in the presence of worst case UWB interference by using a very high UWB device density around the IEEE 802.11a WLAN receiver. The performance of IEEE 802.11a WLAN also needs to be measured and the effectiveness of the various UWB parameters and interference mitigation techniques needs to be compared and verified in a dense multipath environment which is very likely in an indoor environment. This is because application of some parameters/techniques may give low UWB interference and hence better IEEE 802.11a performance in the absence of multipath but may not necessarily perform better in the presence of dense multipath.

1.4 Research Goal

In this research we have investigated the performance of the IEEE 802.11a WLAN in the presence of UWB interference. The various UWB parameters that affect the interference caused to IEEE 802.11a WLAN have been studied and compared with respect to their effect on the performance of IEEE 802.11a WLAN. The effectiveness of the UWB parameters in reducing interference to IEEE 802.11a WLAN has been evaluated in the presence of dense multipath. Two different mitigation techniques that reduce the interference caused by UWB signals to IEEE 802.11a systems have been studied and implemented. The performances of these techniques are then tested in the presence of dense multipath. A comparison between the techniques is provided based on the performance of IEEE 802.11a WLAN.

1.5 Thesis Organization

The rest of the thesis is organized as follows. Chapter 2 gives a brief introduction of UWB technology and the IEEE 802.11a standard. Chapter 3 explains the coexistence issues for UWB with various systems and elaborates the need and various techniques for interference mitigation. Chapter 4 introduces in detail the various UWB parameters that affect the power spectral density of a UWB signal. The power spectrum of UWB signals using different parameters has been observed and compared in Chapter 4. It also introduces two different interference mitigation techniques that can be used to reduce UWB interference to IEEE 802.11a WLANs. Chapter 5 contains the system model of the UWB system, the system model for the IEEE 802.11a WLAN and the system model for the co existence of these two systems. It also contains the simulation parameters for the UWB system, IEEE 802.11a WLAN system and the coexistence scenario. Chapter 5 also presents the simulation results and comparison of the various parameters and the mitigation techniques followed by conclusion and future work in Chapter 6.

CHAPTER 2

UWB AND IEEE 802.11A WLAN

2.1 Ultra Wideband Definition

UWB is defined as any signal whose fractional bandwidth is equal to or greater than 0.20 or that occupies bandwidth equal to or greater than 500 MHz [1] . Here fractional bandwidth is given as $2(F_H - F_L) / (F_H + F_L)$, where F_H is the upper -10 dB cut off frequency and F_L is the lower -10 dB cut off frequency [1]. In this research the impulse radio (IR) form of UWB has been considered. In this form of UWB, generally, pulses of very short duration are sent from the transmitter to the receiver without any form of carrier wave. Carrier can be used but usually carrrierless implementations are preferred to avoid complexity. The extremely short pulse duration results in a very large bandwidth, hence the name Ultra Wideband. These pulse trains have extremely low power spectral densities and have center frequencies in the range of a few giga hertz [2].

Figure 1 shows a part of the UWB spectrum and other systems currently existing at different frequencies inside or near the UWB spectrum. Various shapes of pulses can be used for UWB but the Gaussian pulse and its higher derivatives are currently the most popular and widely used pulse shapes.

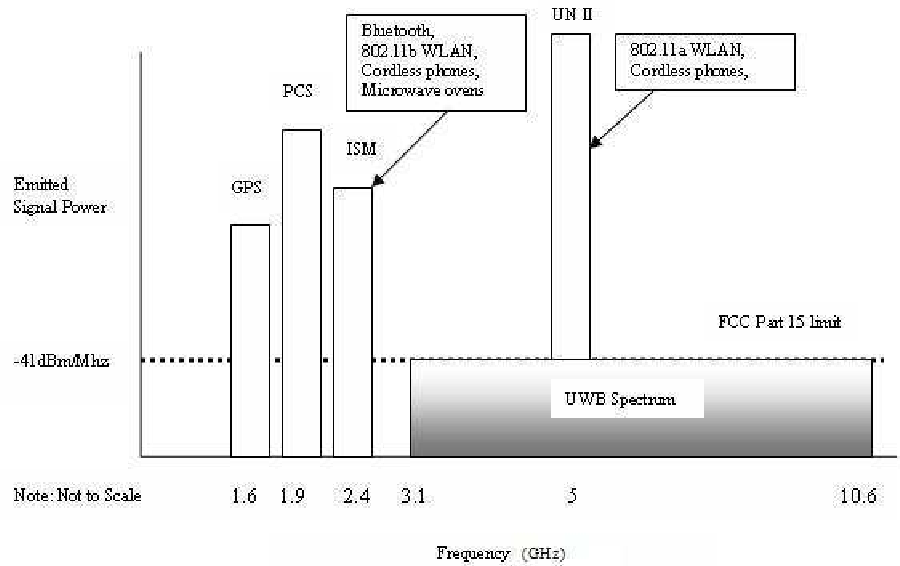

Figure 1. UWB Spectrum and Other Wireless Services. Courtesy [3]

2.2 UWB Characteristics and Applications

Ultra Wide Band signals exhibit some extremely useful and unique features, which have contributed to its popularity in recent years. The most important features of the Ultra Wideband communication [5] are:

a) The bandwidth of the UWB signal is very large and could be used for high data rate applications. With ever increasing demand for high data rate applications UWB devices assume significance.

b) UWB is a very low power signal owing to the FCC restrictions with typical power consumption in microwatts [5]. This characteristic implies a high battery life and/or lighter batteries for UWB devices. UWB signals have low probability of detection, which is of particular interest to military applications [5].

c) UWB receivers are tightly synchronized resulting in better multipath resolution. This characteristic makes the UWB signals very much suitable for precision geo location systems as well as indoor wireless communications [5].

d) The UWB communication systems generally require only DSP components and therefore the system becomes simpler, smaller and lighter in size [5].

e) UWB signals require a non-resonant antenna. Due to this the antenna size is reduced considerably [5].

f) Processing gain is a measure of the radio's resistance to jamming [2] and interference. UWB signals transmit many pulses for a symbol and generally have a large processing gain.

The applications of UWB signals can be classified in to three major areas:

a) Communications: Indoor wireless communications including high speed PANs, Intra home and Intra office communications and military applications [5].

b) Sensors and Radars: This includes applications such as sensor networks, ground penetrating radars, Intrusion Detection Radars, Obstacle Avoidance Radars, and Short-range motion sensing [5].

c) Tracking: This includes precision geolocation systems, inventory tracking, etc [5].

2.3 Transmitter-Receiver Structure

The structure shown in Figure 2 is a specific version of the transmitter and receiver structure for an ultra wideband system given in [2]. Generally the transmitter does not need a power amplifier since the transmitted pulse is generated at the required power by the pulse generator. For some applications a power amplifier may be used. The antenna acts as a filter [2]. The receiver uses a gated correlator, which is tightly synchronized in time to remove any interfering pulses. At the receiver the pulse generator is used to feed the multiplier inside the correlator. The baseband signal-processing block is basically for demodulating and tracking of the signal.

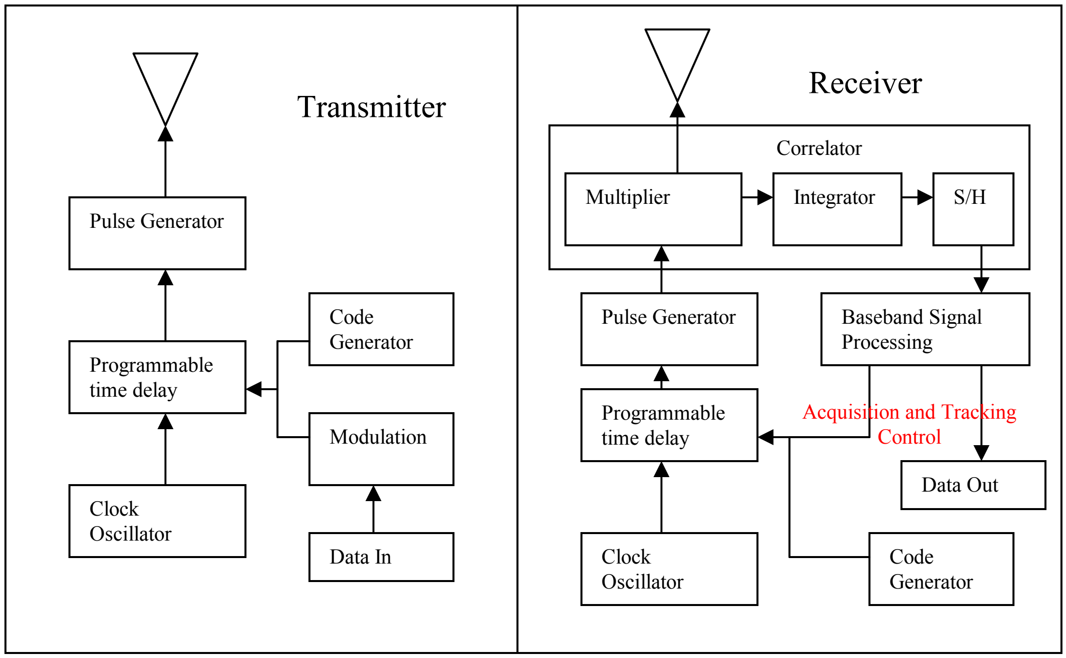

Figure 2. UWB Transmitter-Receiver. Courtesy [2]

The complete UWB communication system consists of the following parts:

Transmitter Section: The transmitter consists of the following parts:

a) Pulse Generator: The pulse generator is used to generate a train of Gaussian pulses of very small duration. These pulses are then modulated by using some type of modulation. In the case of pulse position modulation if the binary data bit to be transmitted is a one then the pulse position is shifted a little earlier than its original position. On the other hand if the transmitted bit is a zero then the pulse position is shifted a little later than the original position. In practice various kinds of pulse generators can be used. Furaxa Inc. has proposed the use of ultra fast electric sampling and pulses [6] for the purpose of generating very high speed pulses. This approach uses multiple pulse generator circuits clustered on a single IC chip and fired off in quick succession by using a string of delay lines. Such circuits can be purposely band limited to avoid any kind of interference with other systems [6]. The pulse train generated by the circuit is a train of regularly spaced pulses and carries no information. Also, because of the repetitive nature of the pulses it produces energy spikes or comb lines in the frequency spectra which are undesirable since it may interfere with other systems [2]. These spikes in the spectra can be reduced considerably by randomizing the position of the pulses with respect to each other. This can be achieved by using pseudo random codes and pulse position modulation (marginally).

b) Modulation: Modulation of the ultra thin pulses is done so that they are able to carry the information with them. As shown in Figure 3 some of the different kinds of modulation schemes that can be used are:

a) Pulse position modulation

b) Bi-phase modulation

c) On-off modulation

d) Orthogonal pulse modulation

Another marginal but important use of the modulation is that modulation of the pulses randomizes the comb like spectrum of the ultra wideband signals and thus helps in smoothening it as shown in Figure 4.

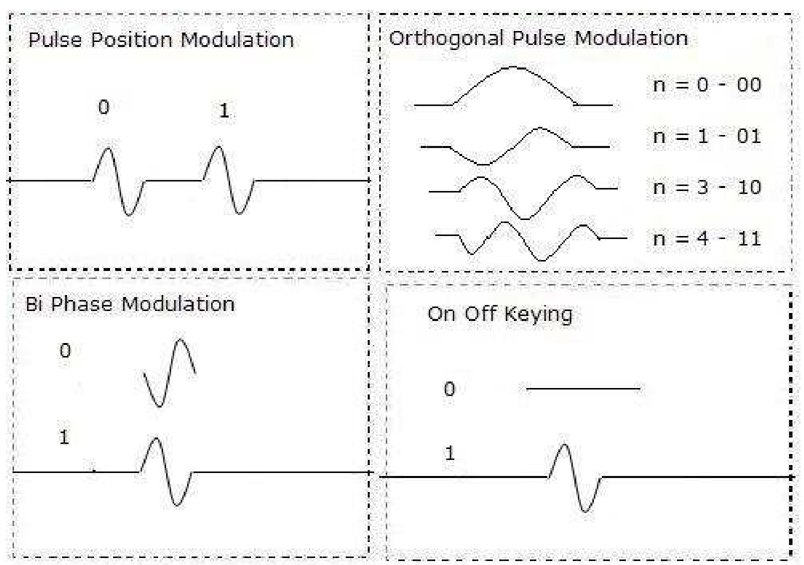

Figure 3. Different Types of Modulation. Courtesy [7]

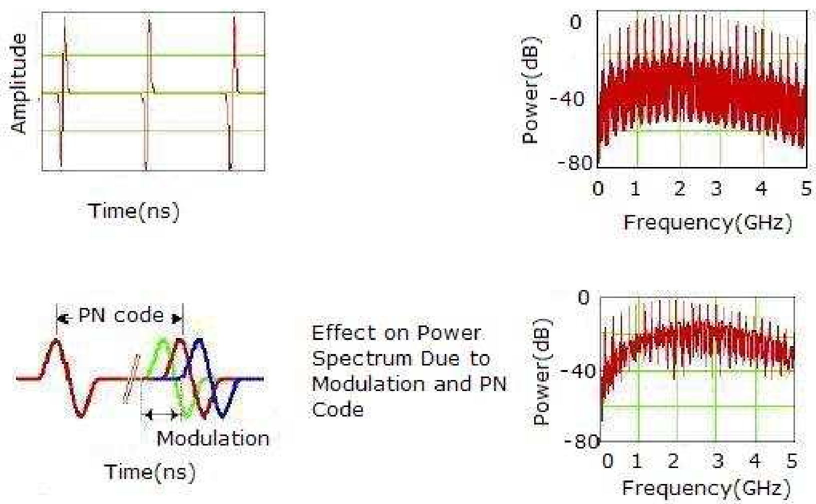

Figure 4. Effect of Modulation. Courtesy [4]

c) PN Code Generator: The PN code generator is a very important part of the transmitter. As discussed earlier in order to flatten the spectrum of the train of pulses the position of the pulses with respect to each other should be randomized. To do this a pseudo random code is generated at the transmitter. The positions of the pulses are changed in accordance with the pseudo random code. The PN codes should be designed in such a way that they have low autocorrelation (near impulse like autocorrelation) as well as low cross-correlation (near impulse like cross correlation). This is very important because in absence of low autocorrelation properties the positions of the pulses will be correlated and this will give rise to periodicity which will introduce spikes in the spectrum. The low cross correlation is important because if the codes of different users are correlated then it will give rise to multi access interference. The cross correlation is also important because when a pilot channel is used then it also requires a PN code and if the PN codes of the data and the pilot are highly correlated then it will be difficult at the receiver to estimate the channel coefficients and the fingers. The transmitter has a unique PN code for each user. The receiver also has the same PN code generator. So when the signal is received the receiver can make out whether the transmitted signal is for that particular receiver.

Receiver section: The receiver section for the ultra wideband communication system consists of the following parts:

a) Correlator: The correlator is one of the most important parts of the IR-Ultra Wideband receiver. It consists of a multiplier, an Integrator and Sample/Hold circuit. The multiplier is used to multiply the received signal with the pulse train randomized by a PN code same as that of the receiver. The integrator is used to sum the energy over all the pulses.

b) Combiner and Demodulator: The combiner and demodulator are for detecting the data from the pulses. The combiner is used to combine the signals over all the taps of the channel. Various types of combining techniques can be used such as maximal ratio combining and equal gain combining.

c) Pulse Generator and PN Code Generator: The pulse generator and PN code generator together produce the signal with which the received signal is correlated.

d) Channel Estimator: The channel estimator is used to estimate the channel coefficients so that the receiver is able multiply the received signal with the reciprocal of the channel coefficients in order to remove the effect of fading.

2.4 IEEE 802.11a Wireless LAN Standard

The IEEE 802.11a standard for high speed physical layer operates in the 5 GHz Unlicensed National Information Infrastructure (UNII) band. The other standards of the 802.11 family operate at 2.4 GHz along with systems such as bluetooth, microwave systems and cordless telephones. The 802.11a standard inherently avoids interference with these systems. The data rate depends upon the modulation technique as well as the encoding scheme. Depending on the combination of modulation and encoding, data rates of 6 to 54 Mbps are possible. The following Table 1 gives all the possible data rates.

Table 1. Modulation Schemes and Coding Rates for Different Data Rates

Data Rate (Mbps)	Modulation	Coding-Rate
6	BPSK	1/2
9	BPSK	3/4
12	QPSK	1/2
18	QPSK	3/4
24	16-QAM	1/2
36	16-QAM	3/4
48	16-QAM	2/3
54	64-QAM	3/4

IEEE 802.11a WLAN uses Orthogonal Frequency Division Multiplexing (OFDM) at the physical layer for transmitting data. In OFDM data is transmitted by dividing the bit stream into parallel bit streams and then modulating each bit stream onto a subcarrrier. These orthogonal subcarriers are then modulated on a single carrier for transmission. The transmission of several symbols in parallel increases the effective symbol time leading to reduction in Inter Symbol Interference (ISI) and a potential increase in data rate. IEEE 802.11a WLAN uses eight channels of 20 MHz each in the lower 5 GHz band and each channel carries data over parallel channels in the form of sub carriers. Each channel is divided in 52 sub carriers of which 4 are pilot channels and 48 are data channels. Figure 5 shows the 802.11a spectrum and channel allocation.

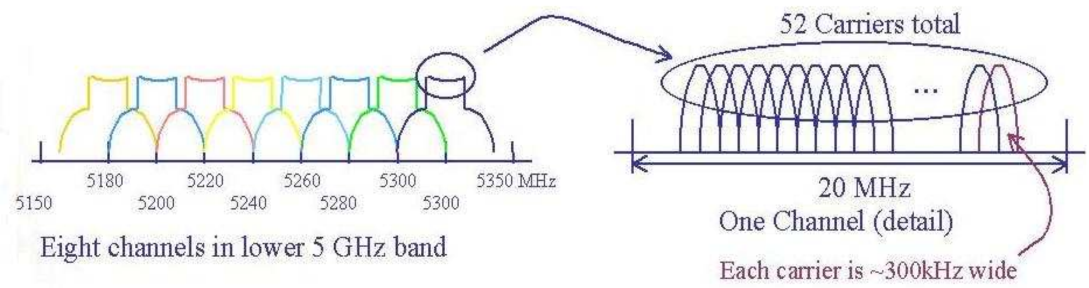

Figure 5. 802.11a Spectrum and Channel Allocation. Courtesy [9]

The 48 sub carriers provide parallel paths for transmitting the data. The 4 pilot sub carriers are used to transmit a known pseudo binary sequence to avoid generation of spectral lines [10]. For a 20 MHz channel with 64 possible sub carrier slots the sub carrier frequency spacing is 0.3125 MHz [10].

The two parts of the OFDM Physical layer are the physical layer convergence protocol (PLCP) and the physical medium dependent (PMD) sub layers [10]. The PLCP communicates with the MAC layer. The data units handed over by the MAC layer are prepared for transmission by the PLCP. The PLCP also passes on the incoming data frames on to the MAC layer. The PLCP acts as an interface between the MAC layer and the PMD layer and packages the data from MAC into a frame format suitable for transmission by the PMD [10]. The PMD then provides the actual transmission and reception between different stations through the wireless medium [10]. The PMD interfaces with the wireless medium and provides modulation and demodulation of frame transmissions [10].

Table 2. Frame Format of IEEE 802.11a

PLLP Preamble (12 symbols)	Rate (4 bits)	Reserved (1 bit)	Length (12 bits)	Parity (1 bit)	Tail (6 bits)	Service (16 bits)	PSBU (payload)	Tail (6 bits)	Pad

The frame format for an 802.11a frame is shown in Table 2. The first 12 symbols in the frame are for the PLCP preamble. The preamble is for synchronization of the OFDM signal at the demodulator. It takes 16 microseconds to train the receiver after first receiving the frame [10].

The signal field consists of 6 fields totaling 24 bits. The first field is the rate field of 4 bits. It defines the data rate to be used. The second field is a reserved bit. This is followed by the length field (12 bits) which defines the frame length. The parity field is one bit based on even parity. The tail is 6 bits (all zeros) to bring the convolutional encoder to zero state [10]. The 802.11a uses binary phase shift keying (BPSK), quadrature PSK (QPSK), or quadrature amplitude modulation (QAM) depending on the chosen data rate (refer Table 1) [10]. However the preamble is convolutionally encoded and always sent at 6 Mbps using BPSK irrespective of the data rate specified in the signal field.

The encoded data duration is 3.2 μs and the guard interval is 0.8 μs. For BPSK modulation the highest bit rate that can be achieved on a sub-channel is 250 kbps. Therefore for 48 channels the altogether bit rate is 12 Mbps. If 1/2 rate convolutional code is used, 6 Mbps is achieved for lowest data rate. The highest rate, namely 54 Mbps, is achieved as follows. 64 QAM is used where each modulated symbol carries 6 bits [11]. The throughput of 3/4 rate codes is 3/2 times greater than the throughput of 1/2 rate codes. If we multiply these two, 9 times faster rate is obtained than the basic 6 Mbps system, i.e., 54 Mbps [11].

The signal field is followed by the service field of 16 bits. The first six bits of the service filed are for synchronization of the descrambler at the receiver and the remaining are for future use and are currently set to zeros. This is followed by the actual payload data unit which is being sent from the MAC layer. The pad field contains at least six bits, but it is actually the number of bits that make the data field a multiple of the number of coded bits in an OFDM symbol (48, 96, 192, or 288) [10]. A data scrambler scrambles all the bits in the data field to avoid long sequences of zeros or ones.

Operating frequencies for the 802.11a OFDM layer fall into the following three 100-MHz UNII bands: 5.15 to 5.25 GHz, 5.25 to 5.35 GHz, and 5.725 to 5.825 GHz [10]. There are twelve 20-MHz channels, and each band has different output power limits as shown in Table 3 [10].

Table 3. IEEE 802.11a OFDM Operating Bands and Channels

Band	Channel numbers	Center frequency (MHz)	Maximum output power (with up to 6 dBi antenna gain)
U-NII lower band (5.15 to 5.25 MHz)	36 40 44 48	5180 5200 5220 5240	40mW (2.5mW/MHz)
U-NII middle band (5.25 to 5.35 MHz)	52 56 60 64	5260 5280 5300 5240	200mW (12.5mW/MHz)
U-NII upper band (5.725 to 5.825 MHz)	149 153 157 161	5745 5765 5785 5805	800mW (50mW/MHz)

The 802.11a standard requires receivers to have a minimum sensitivity ranging from -82 to -65 dBm, depending on the chosen data rate [10]. The lower frequency bands have very low power limits and are therefore most sensitive to range losses as well as interference.

CHAPTER 3

COEXISTENCE ISSUES

3.1 Introduction

UWB is an emerging technology for use in the indoor wireless personal area networks and ad hoc networks. However one of the main obstacles facing the implementation of this technology is the challenge of mutual interference reduction. UWB signals, generally, have a very large bandwidth that occupies the frequency spectrum from 3.1 to 10.6 GHz. It is very important to minimize the interference of UWB systems to all the other systems that currently exist or may exist in the future in the UWB frequency spectrum and vice versa. Many systems such as GSM, CDMA, IEEE 802.11a and IEEE 802.11b WLANs etc. currently exist in or near the UWB frequency spectrum.

3.2 UWB and CDMA

The effect of interference of UWB devices on the BER performance of a CDMA system has been analyzed in [12]. The author concludes that the interference caused by UWB devices depends on various factors such as the pulse repetition period of the UWB signal and the frequency band of the CDMA system. It has been shown through theoretical analysis and simulation in [12] that the interference caused by a single UWB device to the CDMA system is very low and almost negligible. However for multiple UWB devices the chances of causing interference are high because the number of spectral peaks in the UWB spectrum increase and such a spectral peak can cause the BER of CDMA receiver to degrade [12]. In-band interference power caused by UWB signals at the frequency bands of the

UMTS/WCDMA systems has also been studied in [13]. Different pulse waveforms are used and the frequency spectra of UWB signals are measured. It has been shown in [13] that just by using different pulse widths and different pulse waveforms (without using any filtering) it is possible to avoid UWB interference in the UMTS band. The author reports that it is possible to produce spectral nulls in the UWB spectrum by using a Gaussian doublet. The separation between the pulses in the Gaussian doublet depends upon the data rate requirement as well as the frequency band at which the spectral null is to be produced. It has been shown that narrowing the pulses in time can produce better results from an interference point of view [13].

3.3 UWB and GSM

Interference of UWB to a generic narrowband receiver has been studied in [14]. The author states that the BER performance of the narrowband receiver depends on a number of factors such as UWB modulation, UWB pulse repetition frequency, center frequency of the narrowband system and the narrowband matched filter. It has also been shown in [14] that by using the proper modulation schemes, proper pulse repetition rates (PRFs) and proper positioning of the PRF with respect to the center frequency of the known narrowband signal in the UWB spectrum, the interference from UWB can be reduced considerably.

In [15], the coexistence of UWB with existing radio services in the 3.1 to 10.6 GHz frequency band has been studied, In particular the interference caused by UWB to fixed wireless access (FWA) services (GSM, IMT2000, Bluetooth etc.) has been studied. The implementation of different interference mitigation techniques applicable to any UWB device was reported. The interference mitigation techniques studied are generic and can be applied to any UWB scheme. Techniques such as 1) Power control, 2) Activity of the radio device, and 3) Effective path link dynamics have been implemented and found to reduce the UWB interference power by as much as 35 dB in worst case conditions [15]. Using these interference techniques, it has been shown that in worst case conditions peaceful coexistence of UWB system with FWA services is possible.

The PSD of UWB signals has been studied in [16]. The author states that in addition to the PSD of the UWB signals, other factors such as the 1) Spatial density of the UWB transmitters and 2) The traffic characteristics of the network of UWB transmitters need to be taken in to consideration for the calculation of the total interference power levels caused by the UWB signals.

The interference caused by UWB to GSM systems has been analyzed in [17]. The Antenna of GSM system is generally placed very high and quite a distance away from the GSM Phone. The UWB devices would be deployed mostly indoor and near the GSM phone. It has been observed in [17] that the UWB signal is too weak at the GSM antenna to cause any significant interference. Therefore, according to [17] the uplink signal for GSM systems remains unaffected by UWB interference. However, the GSM phone and the UWB devices operate in close proximity. Therefore the downlink case needs to be observed for interference from UWB devices. Assuming a UWB device density of 0.2 UWB transmitters/m^2 the study in [17] indicates that for GSM 900 systems there is no significant interference from UWB devices. This is because both the FCC and ETSI regulations for UWB transmitted power are sufficient to reduce UWB interference to negligible. This is also true in most cases for GSM 1800. However for the phones operating on the cell boundary for GSM 1800, the FCC limit on out of band power for UWB (power outside the 3.1 – 10.6 GHz spectrum) becomes inadequate [17].The ETSI regulations, however, are more stringent and therefore are sufficient for both the cases of GSM 900 and GSM 1800 in all conditions.

3.4 UWB and WLANs

The interference caused by UWB to WLAN systems has been analyzed in [17]. The WLAN systems that have been considered in [17] are IEEE 802.11a and IEEE 802.11b systems. It was observed that both the systems are severely affected by the interference from the UWB systems. However the author mentions that the coexistence of IEEE 802.11a and the UWB systems will be almost impossible as IEEE 802.11a systems operate inside the UWB spectrum. It has been observed that for a single continuously transmitting UWB device the minimum distance of the UWB transmitter from the IEEE 802.11a Access Point needs to be 6 meters for SNR loss to be below 6 dB [17] . The device density is kept at 0.2 UWB transmitters/m^2 . The interference caused by UWB to IEEE 802.11a and IEEE 802.11b systems has been shown in Figure 6. It has been observed in [17] that the range of 802.11b devices is halved in the presence of UWB transmitters following the ETSI regulations, and the range is reduced by a factor of four in presence of UWB transmitters following the FCC regulations. For IEEE 802.11a, the reduction in the range is by a factor of 7 [17]. In the absence of UWB interference IEEE 802.11a systems perform better than the IEEE 802.11b systems, however in the presence of UWB interference IEEE 802.11b systems provide higher throughput for distance greater than 20m as compared to IEEE 802.11a systems [17].

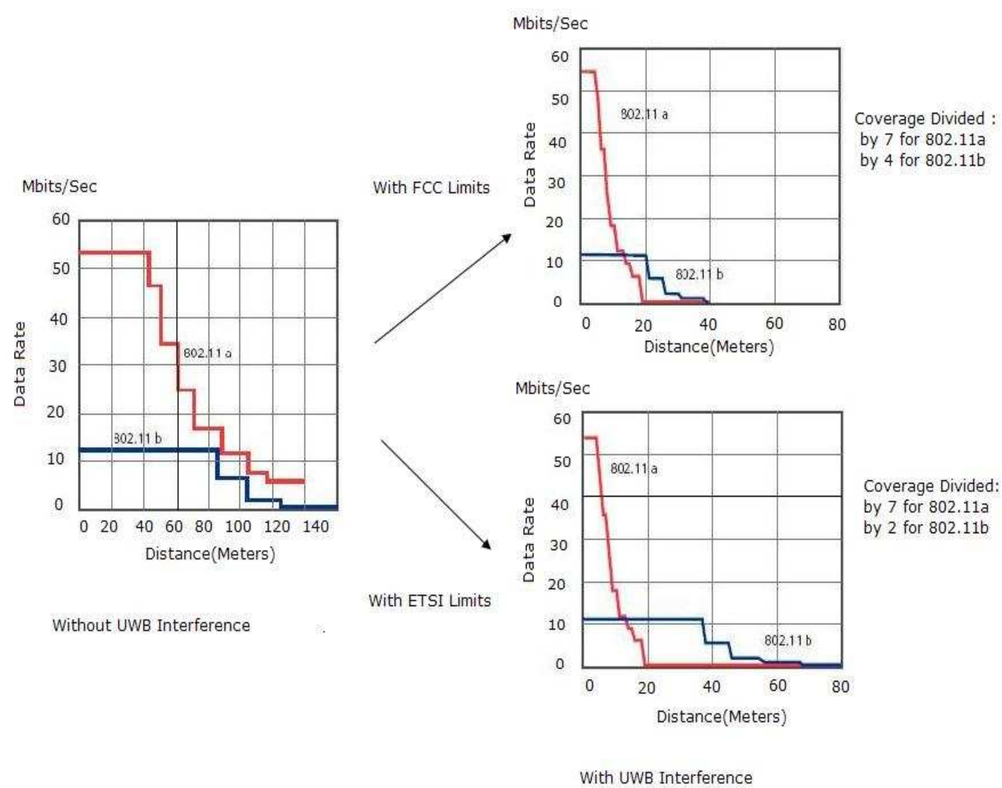

Figure 6. UWB Interference to IEEE 802.11a and IEEE 802.11b. Courtesy [17]

Coexistence of UWB with IEEE 802.11a systems is one of the biggest challenges that we face today. The performance of an IEEE 802.11a system in the presence of UWB interference has been observed in [18]. The performance of IEEE 802.11a system was found to be severely affected by the UWB interference as long as the UWB transmitters are in close vicinity of the IEEE 802.11a receivers. However as the UWB transmitters move away from the IEEE 802.11a receivers the effect of the interference becomes less and less [18]. Other studies such as [19] have also evaluated the coexistence of UWB with IEEE 802.11a systems. It was observed in that for a line of sight (LOS) case the performance of IEEE 802.11a system is unaffected by the UWB interferers even if they are in close range. However for the non line of sight (NLOS) case the UWB interference severely impacts the performance of IEEE 802.11a performance [19]. Also it has been observed in [19] that the performance of the UWB receiver degrades by about 36 dB in presence of a LOS IEEE 802.11a interferer.

We have seen here that a number of attempts have been made to model the effect of UWB interference on the performance of IEEE 802.11a WLAN. However the UWB parameters that affect the performance of IEEE 802.11a WLAN have not been compared with respect to the throughput and BER performances of an IEEE 802.11a WLAN. The effectiveness of these UWB parameters and other UWB interference mitigation techniques in reducing the interference caused to IEEE 802.11a WLAN in the presence of dense multipath remains to be investigated. The goal here is to study the variousUWB parameters and mitigation techniques that are effective for reducing the interference power of UWB signals. The UWB parameters are then modified in order to achieve the desired spectral properties and a minimal interference to IEEE 802.11a OFDM WLAN. Different modulation techniques, spreading techniques, PRFs, pulse shapes, pulse widths have been compared with respect to performance of IEEE 802.11a OFDM WLAN. The performance is also monitored in presence of dense multipath channel. The two mitigation methods of spectral subtraction and PN design are compared with .respect to their effect on the performance of the IEEE 802.11a OFDM WLAN.

CHAPTER 4

UWB PARAMETERS AND TECHNIQUES FOR INTERFERENCE MITIGATION

4.1 UWB Parameters

The PSD of UWB signals is affected by a number of parameters:

a) Pulse Shape and Duration.

b) Pulse Repetition Period.

c) Spreading Technique.

d) Spreading Code.

e) Modulation.

f) Multipath.

a) Pulse Shape and Duration

In [20], it was shown that higher derivative pulses (of the Gaussian pulse) have a lower PSD than the lower derivative pulses. For the same pulse width, the energy of higher derivative of Gaussian pulse is concentrated in a narrower window of time than that of the Gaussian monopulse as shown in Figure 7 and Figure 8. This means that for the same pulse width the higher derivative of Gaussian pulse spreads the energy more along the frequency spectrum than the Gaussian monopulse. Figure 9 and Figure 10 show that for a pulse width of 0.2 ns the fourth derivative of Gaussian pulse reduces the interference power by almost 7 dB as compared to the Gaussian monopulse. Another parameter of interest is the pulse width. The power of a narrow pulse is distributed over a wider range of frequencies. This can be useful from an interference point of view. The spectrum of a UWB signal has more power at its center frequency than at the boundaries. And narrowing the pulse in time increases the bandwidth of the UWB signal and moves the center frequency towards higher frequencies. Figure 10 and Figure 12 show that for given pulse shape (fourth derivative of Gaussian pulse) the pulse with a width of 96.15 ps reduces the interference power by almost 21 dB as compared to the pulse width of 0.2 ns. Since we are concerned about WLAN IEEE 802.11a system, any pulse width which moves the center frequency of the UWB signal farther away from the operating frequency of the IEEE 802.11a system is of interest to us.

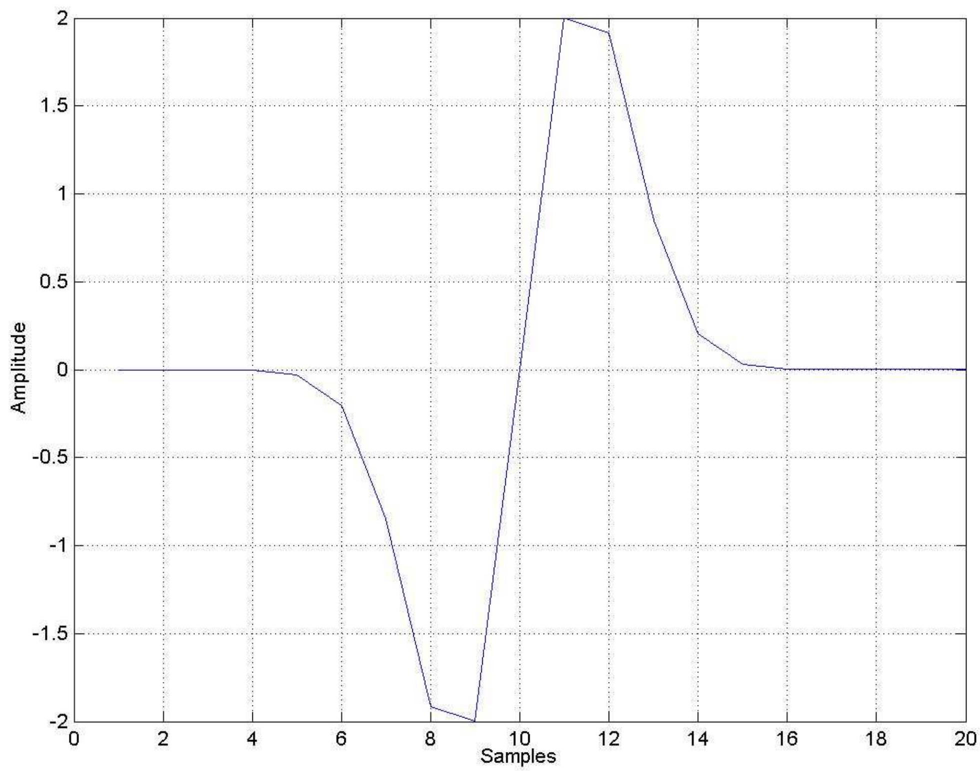

Figure 7. Gaussian Monopulse

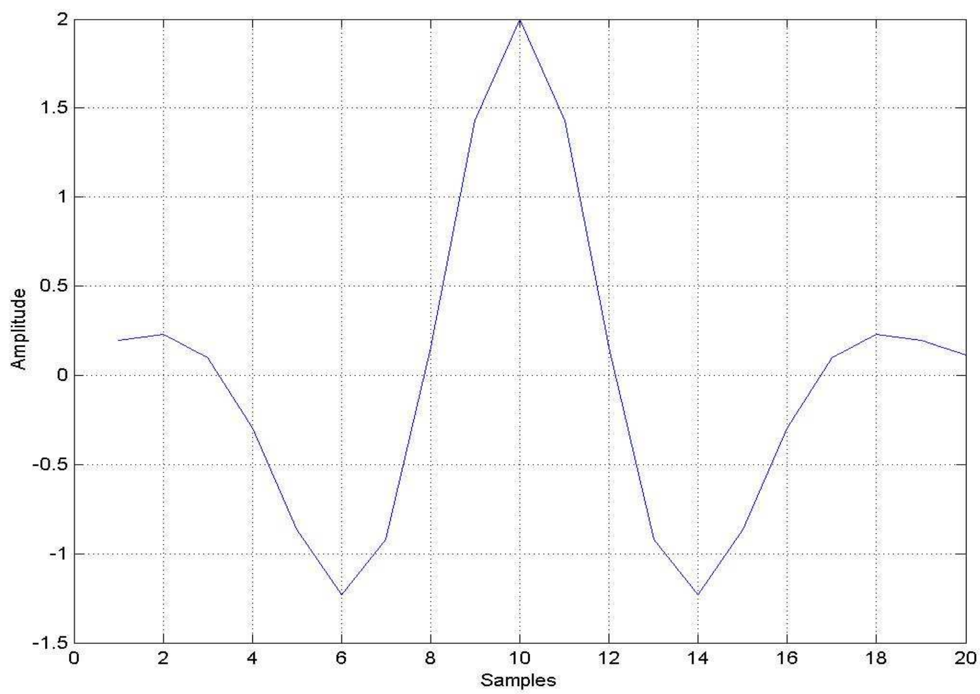

Figure 8. Fourth Derivative of Gaussian Pulse

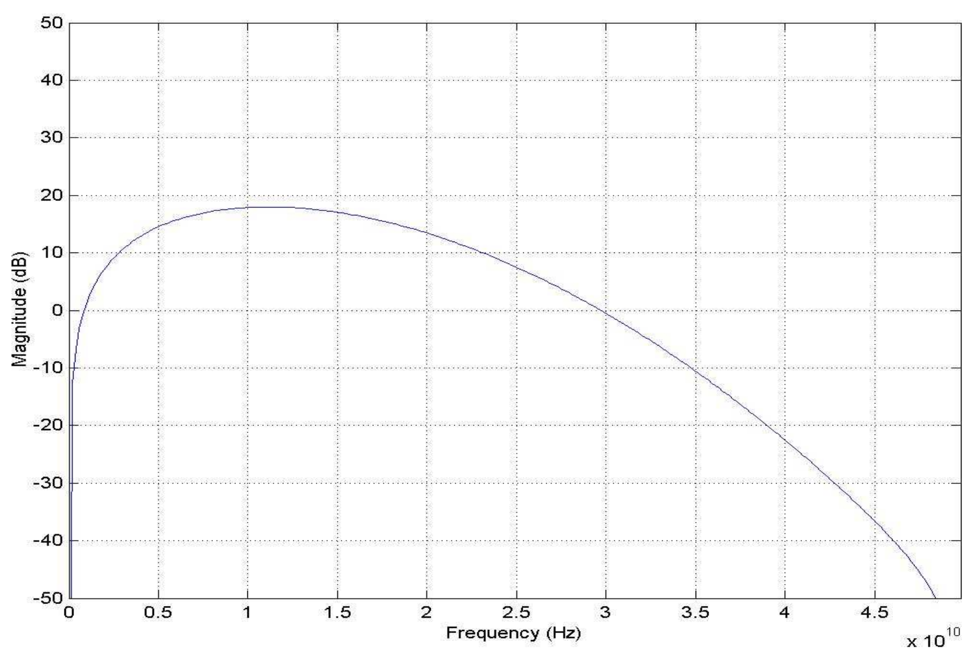

Figure 9. Power Spectrum of Gaussian Monopulse (0.2 ns)

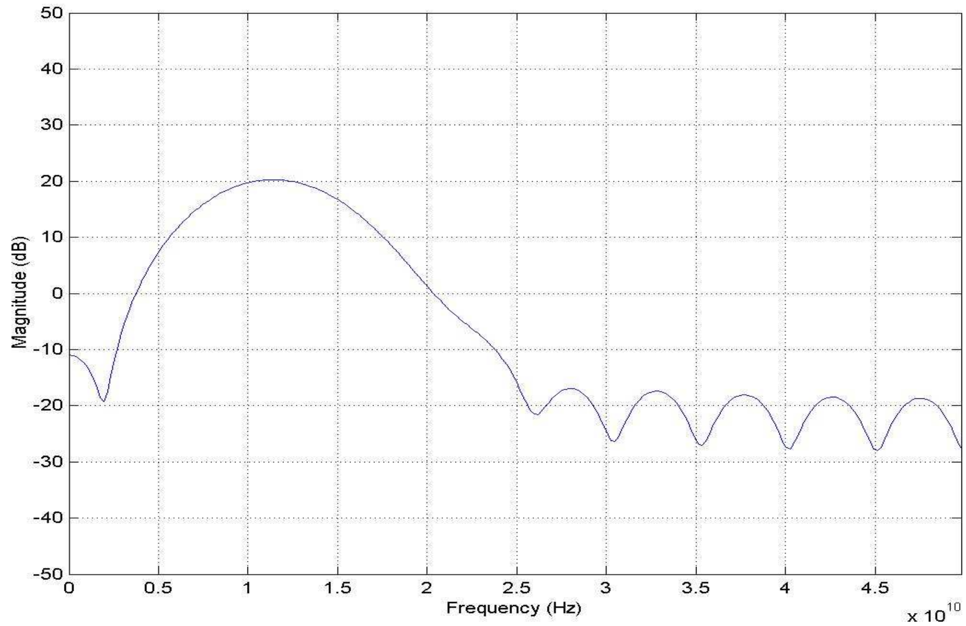

Figure 10. Power Spectrum of Fourth Derivative of Gaussian Pulse (0.2 ns)

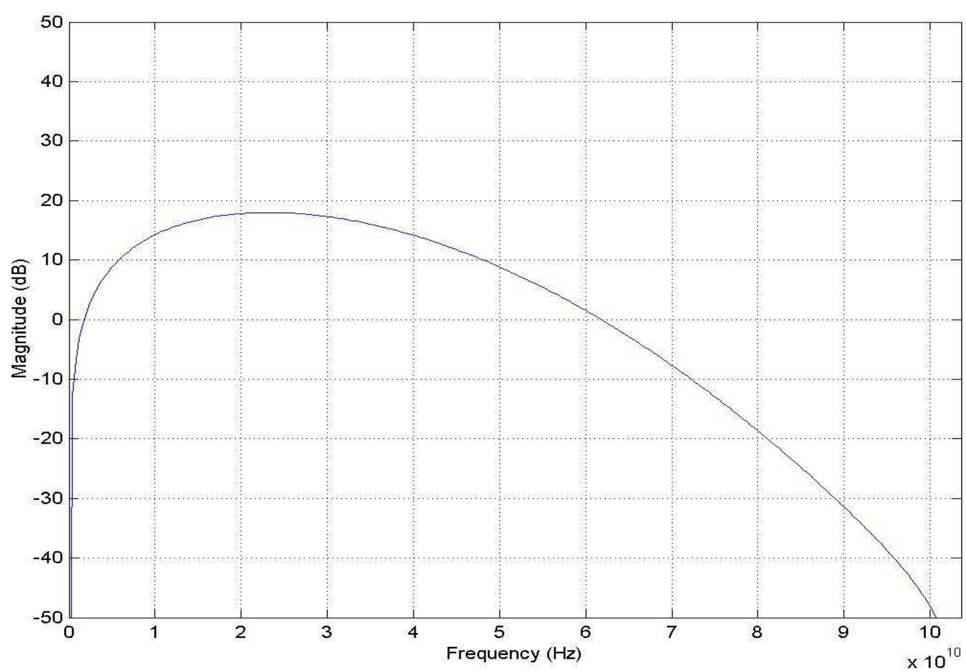

Figure 11. Power Spectrum of Gaussian Monopulse (96.15 ps)

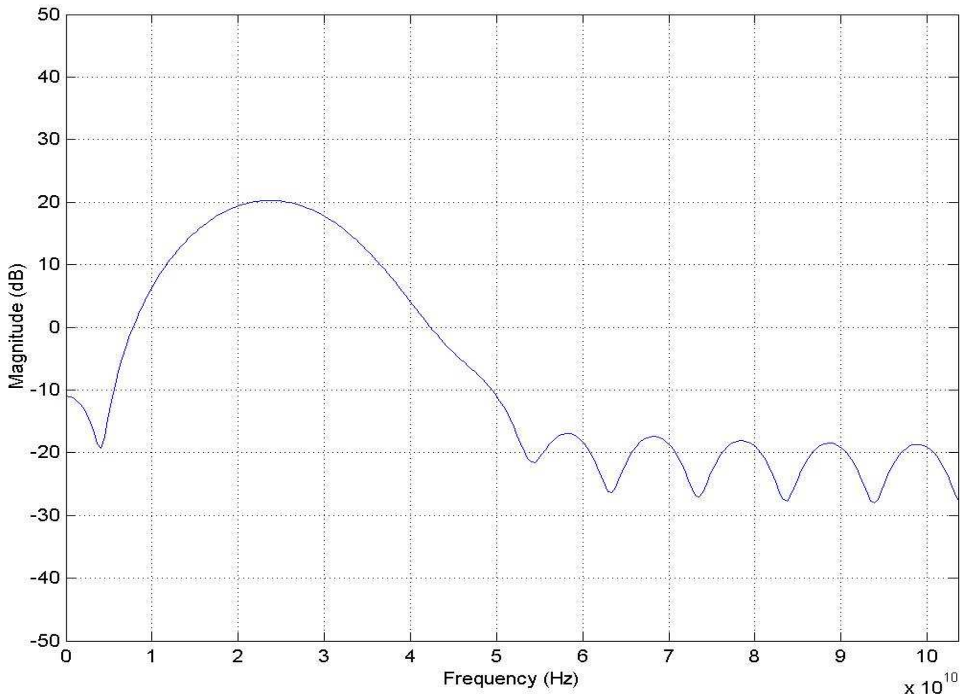

Figure 12. Power Spectrum of Fourth Derivative of Gaussian Pulse (96.15 ps)

We have considered two pulse shapes namely the Gaussian monopulse and the fourth derivative of the Gaussian pulse. Both these pulse shapes are used with the TH-IR spreading in UWB transmitters operating in close proximity of the 802.11a STAs. The performance of the WLAN system is then monitored in the presence of the UWB interference to see the effect of the pulse shapes on the WLAN 802.11a performance. To study the effect of pulse width we have used two different pulse widths for the same pulse shape (fourth derivative of the Gaussian pulse) and compared the performance of the IEEE 802.11a system which is being interfered by the UWB devices using the two different pulse widths.

b) Pulse Repetition Period

Pulse repetition period (PRP) defines the amount of time after which a pulse repeats itself in the UWB symbol. For a given data rate if the pulse repletion period is small (pulse repetition frequency (PRF) is large) then there are more number of UWB pulses per symbol. Due to more number of pulses the interference power level of the UWB signal also increases if the PRP is small (PRF is large). We can verify this from Figure 13 and Figure 14. As we can see that a PRF of 16.66 MHz offers a 15-20 dB reduction in interference power as compared to a PRF of 100 MHz. A low interference power should result in a better performance of the affected system. However research by forester in [14] provides an interesting perspective. The results show that if the pulse repetition period is low (pulse repetition frequency is higher than the narrowband receiver frequency) then the interference caused by such a UWB device will be uniformly distributed over the symbol time of the narrowband system. Thus for a high PRF the UWB interference can be modeled as a white Gaussian noise which can be averaged out by the narrowband receiver thus reducing the BER and improving the performance [14]. However for a UWB system with a PRF which is lower than the narrowband receiver frequency the interference produced is not uniformly distributed and therefore the receiver cannot average it out very well and is more prone to errors [14]. In our case the narrowband system of interest is the IEEE 802.11a WLAN. The IEEE 802.11a receivers have a frequency of 20 MHz. Therefore we have considered two PRF's. One PRF is greater than 20 MHz and the other PRF is less than 20 MHz. Using these two PRFs in UWB systems that interfere with the IEEE 802.11a system we have compared the performance of the IEEE 802.11a to determine which PRF performs better with respect to throughput and BER performance of IEEE 802.11a.

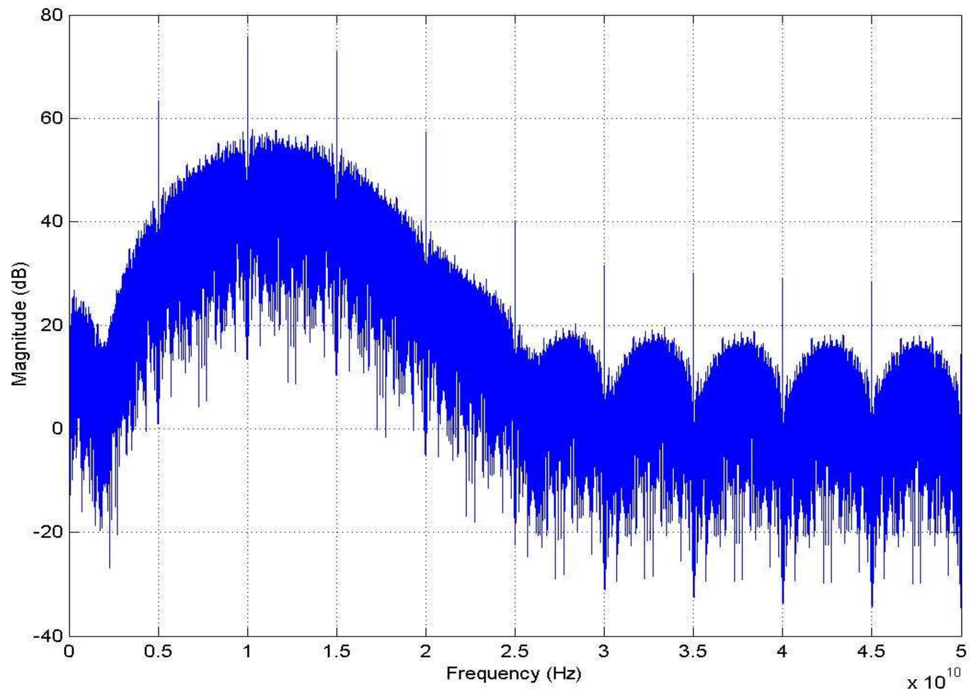

Figure 13. Power Spectrum for UWB Signal with PRF High (100 MHz)

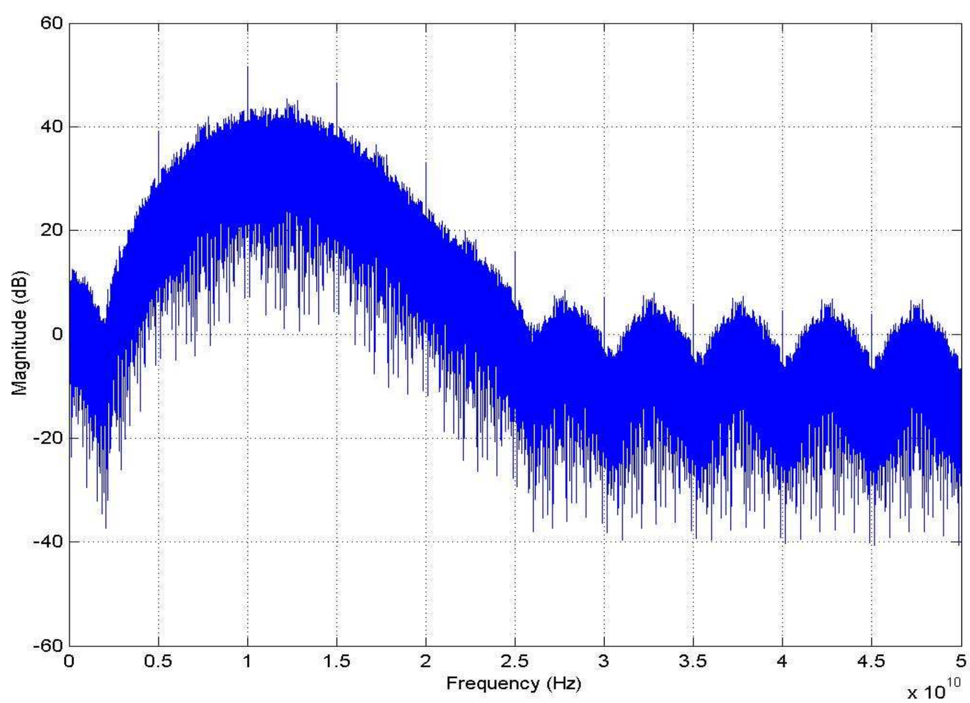

Figure 14. Power Spectrum for UWB Signal with PRF Low (16.66 MHz)

c) Spreading Technique

In [21], it was shown that direct sequence spread spectrum systems have lower PSD levels than time hopped systems. Figure 15and Figure 16 show that for a single tap channel (direct path) the power spectrum of DSSS-UWB is much smoother than that of TH-IR UWB. Also DSSS signals can provide a higher data rate than TH-IR signals for a given length of the spreading code [22]. However for a moderate data, the TH signal may be potentially less susceptible to nearfar effect than the DSSS signal [8]. The main topic of interest of this research is how to reduce the interference produced by UWB system to the IEEE 802.11a OFDM WLAN system without reducing the performance of the UWB system itself. Although DSSS seems to reduce the effect of multi-user interference, it remains susceptible to narrow band interference and multipath [23]. This effect of multipath will be even more pronounced at the STAs of the 802.11a WLAN system because there we do not have any mechanism to resolve this multipath and the UWB signal (from all the paths) gets added as interference. Therefore it is essential to determine which spreading technique produces less interference to WLANs in the presence of multipath and which system produces less interference in the absence of multipath. We have considered both the cases. In one case a single tap channel has been used for UWB while in the other case a 30 tap channel (30 paths) is used and again the performances of IEEE 802.11a are measured.

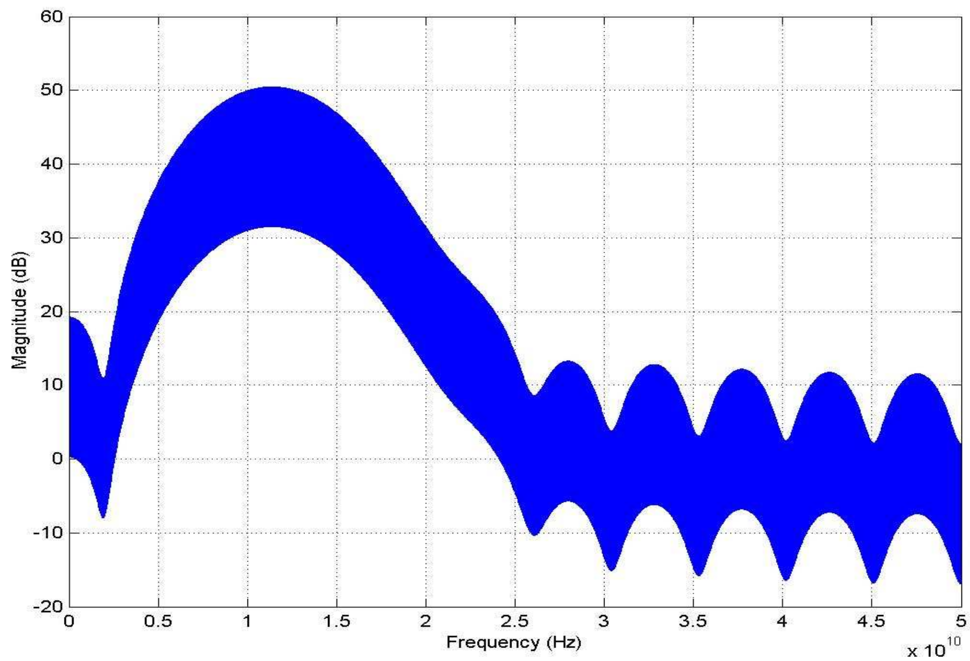

Figure 15. Power Spectrum of DSSS UWB in a Single Tap Channel

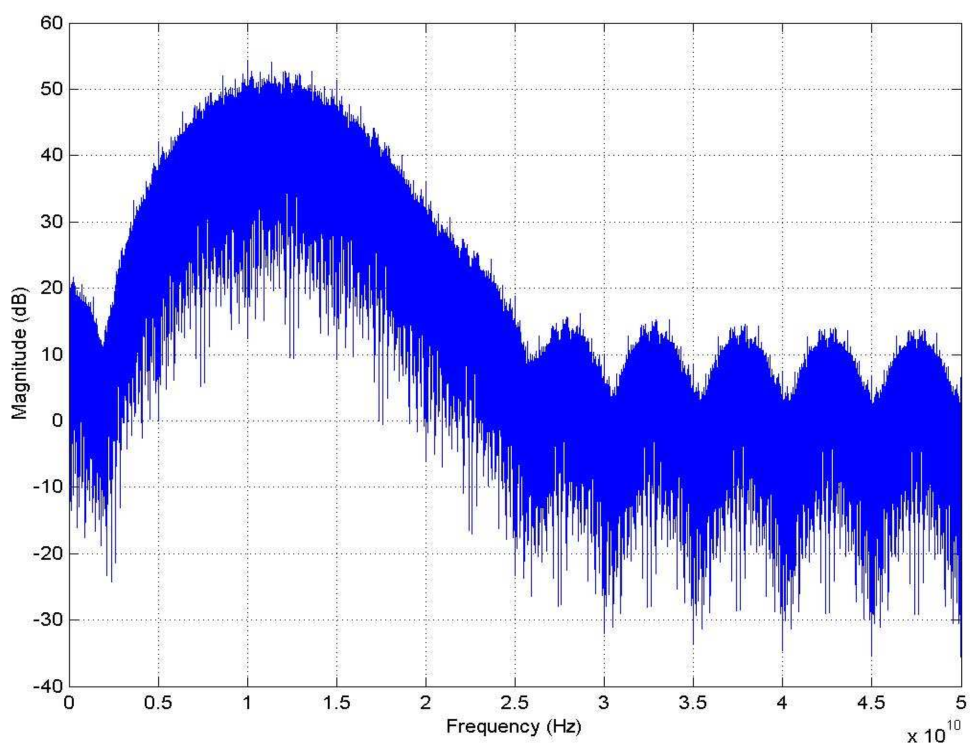

Figure 16. Power Spectrum of TH-IR UWB in a Single Tap Channel

d) Spreading Code

We have considered the case of TH-IR to study the effects of different PN codes on the performance of the WLAN 802.11a system. A very novel approach to removing narrow band interference in UWB systems has been proposed in [24]. The same approach can also be used to reduce the interference of UWB systems to other narrowband systems such as the 802.11a. This approach involves designing a TH code such that the contribution of PSD of this code to a particular frequency band is extremely low or negligible. One such code has been designed in [24]. The code is a concatenation of locally optimal codes designed for each symbol in a UWB packet. Suppose that we have a UWB packet length of 7 symbols then we will have seven locally optimal codes which will have a minimal contribution to the frequency band which needs to be omitted. It has been proven in [24] that the concatenation of these codes will produce a longer code which will still have negligible contribution to the concerned frequency band. This code is used with UWB systems which are interfering with the WLANs and the performance of the WLAN system is monitored. We have also tested the codes for different order of concatenation and found out that the order of concatenation of the locally optimal codes has little impact on the PSD of the concatenated code and therefore can be used as an orthogonal code. Figure 17and Figure 18 show that the power spectrum of the UWB signals using the original code and the code with changed order of concatenation are almost identical at the frequency band of interest. Thus from a single code for 7 symbols for one user we can derive 7 orthogonal codes for 7 users each. These codes can then be used for 7 different users with negligible collision. For analysis puposes the efficiency of this code is compared with that of the spectral nulling method for the performance degradation of IEEE 802.11a OFDM WLAN system.

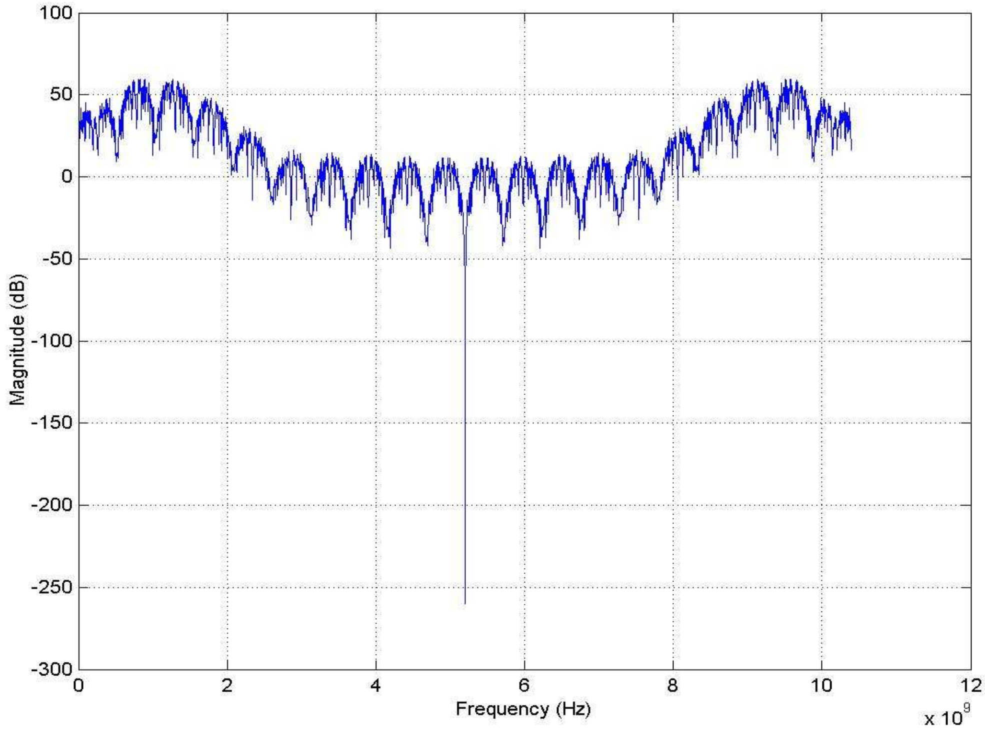

Figure 17. Power Spectrum of UWB Signal with PN Code Designed in [24]

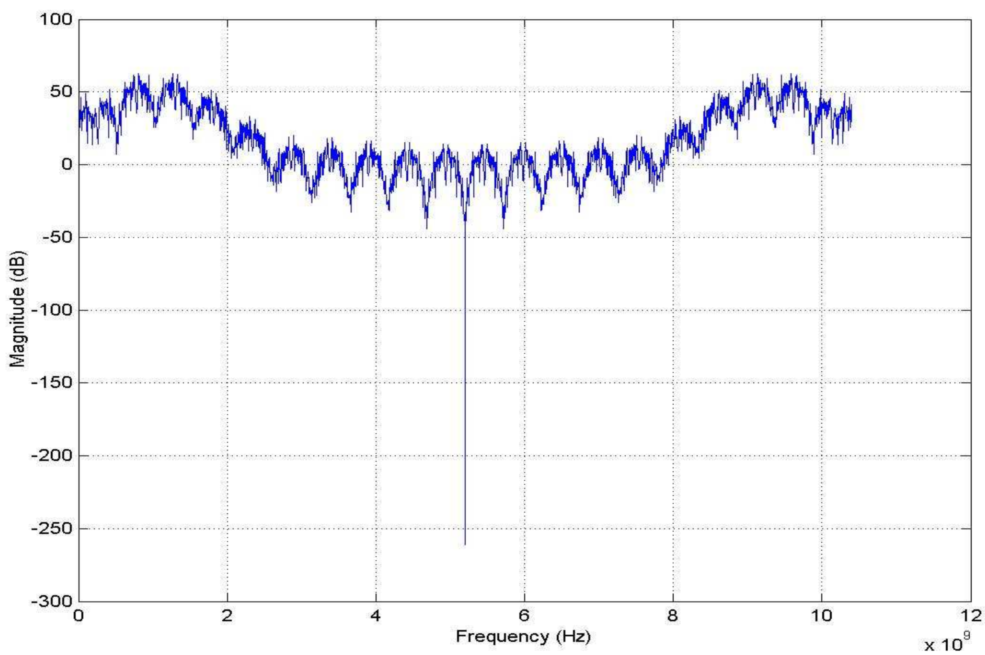

Figure 18. Power Spectrum of UWB signal with Changed Order PN Code

e) Modulation

UWB-TH-IR has been used with different modulation techniques for comparison. While pulse position modulation has been the most widely used with UWB so far, recent studies [25] suggest the need to explore other modulation schemes. Comparison of pulse position modulation (PPM), biphase modulation (BPM) and hybrid modulation in [25] suggests that PPM has discrete spectra that can cause interference to other systems while BPM and hybrid schemes have continuous spectra. We have compared the spectra of UWB signals for these modulation techniques and found that the spectrum of BPM has less spectral lines than PPM. Also on off keying (OOK) was tested and its spectrum was found to be lower than the spectrums of both PPM and BPM modulated signals.Figure 19, Figure 20, and Figure 21 show the spectrum of UWB signal using PPM, BPM and OOK, respectively. All of these modulation schemes were applied to the interfering UWB signal and then the throughput and BER performances of the WLAN system were measured.

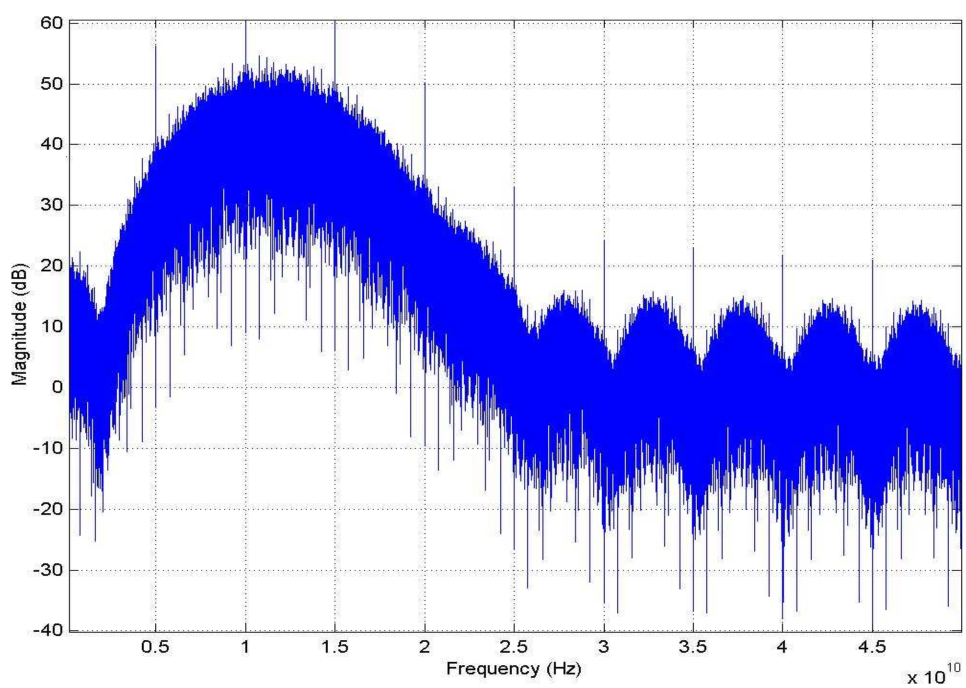

Figure 19. Power Spectrum of UWB Signal with PPM Modulation

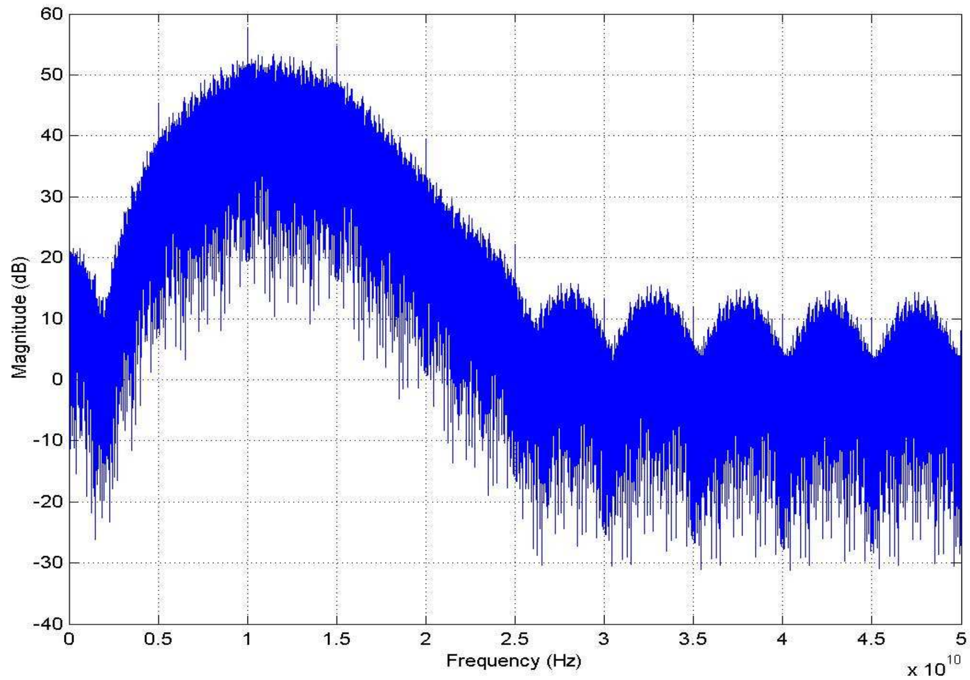

Figure 20. Power Spectrum of UWB Signal with BPM Modulation

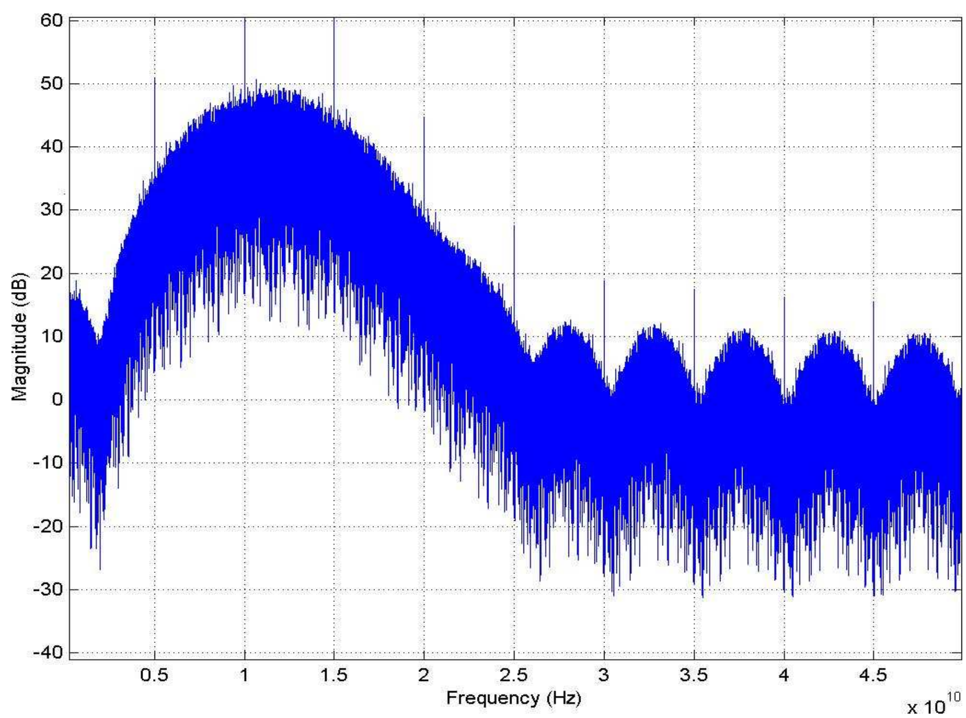

Figure 21. Power Spectrum of UWB Signal with OOK Modulation

f) Multipath

Even though multipath is not exactly an UWB parameter and does not affect the PSD of the transmitted UWB signal we have considered it here because it is one of the most important characteristics affecting the performance of WLAN system. If we have a multipath channel then the noise level at the receiver is increased owing to addition from the different paths. Performance of DSSS UWB systems degrades more with increasing multipath TH-IR UWB systems. The degradation in the presenceof multipath (30 taps) as compared to that in absence of multipath for for DSSS UWB systems is about 20 dB (see Figure 22 and Figure 23) while for TH-IR UWB system degradation is about 15 dB (see Figure 15 and Figure 22).

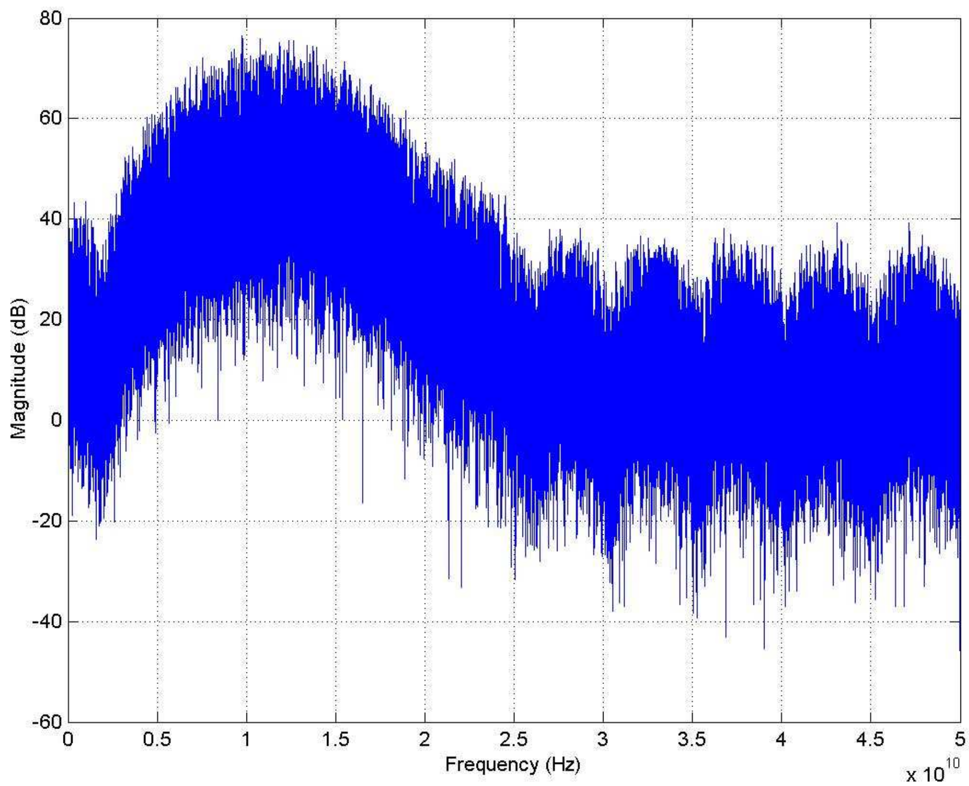

Figure 22. Power Spectrum of DSSS-UWB Signal with 30 Tap Channel

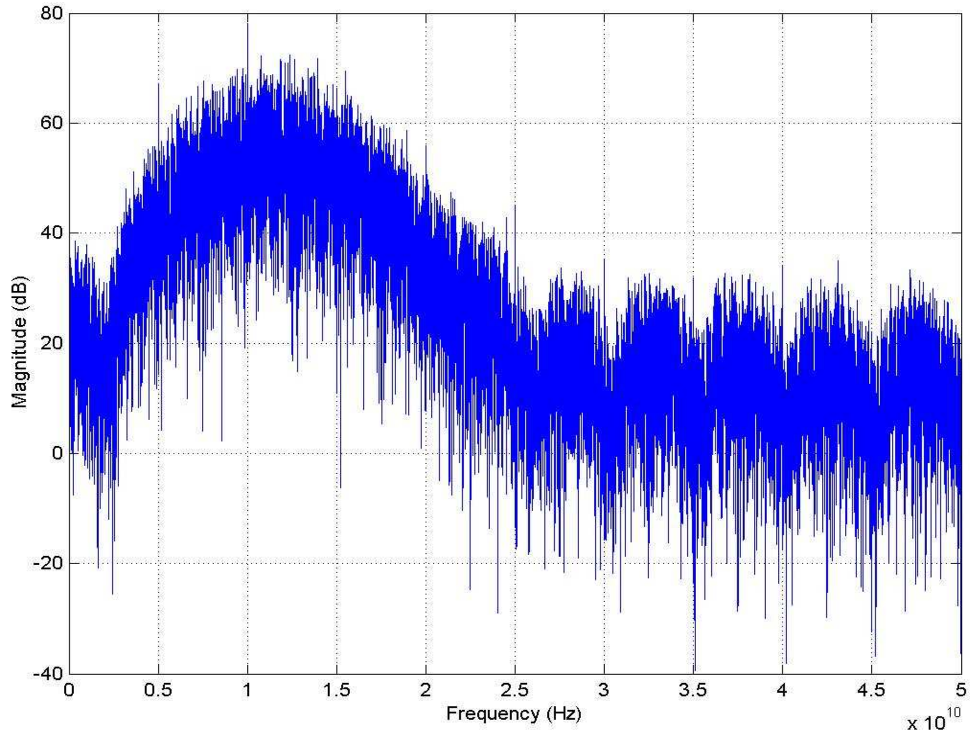

Figure 23. Power Spectrum of TH-IR UWB Signal with 30 Tap Channel

Thus we can see a 5 dB increase of interference power from DSSS-UWB as compared to TH-IR UWB. All the parameters and mitigation techniques need to be compared in the presence of dense multipath channel to examine the performance of IEEE 802.11a. We have used a channel model with two configurations one with single tap and one with 30 taps. The UWB signals are then passed through these channels before being added at the receiver of the IEEE 802.11a system. The performance of the IEEE 802.11a is then compared with and without multipath interference.

4.2 UWB Interference Mitigation Techniques

Various techniques have been proposed and implemented to limit the power of UWB signals and also to shape the spectrum of the UWB signals such that there is minimal or no interference at the frequency spectrum of other systems. The methods for interference mitigation can be classified into different categories as in [26] for the purpose of a systematic analysis. We have grouped these methods into three classes:

a) Spectral Subtraction Technique

b) PN Sequence Design

c) Multiband Techniques

a) Spectral Subtraction Technique

In this method the required spectral properties are achieved at the transmitter by performing spectral subtraction or spectral nulling. The signal with the desirable spectral characteristics is then deconvolved with the original UWB signal to get the sytem function or impulse response h(t) which modifies the signal. The modifying impulse response and the signal with the desired spectral properties are then transmitted to the receiver side, where before demodulation the signal with the desired spectrum is then deconvolved with h(t), i.e., the spectrum modifier to get the original transmitted signal. This approach is similar to a two stage filter design approach proposed in [27]. Another approach for spectral shaping using filter design with neural networks is proposed in [21].

b) PN Sequence Design

A very novel PN sequence design has been suggested in [28]. The period of PN sequence is extended and the signals generated using this extended PN sequences are found to have near flat PSD [28]. In [29], an analytical framework was developed for the PSD of UWB signals which could be used for the design of Time Hopped Pseudo Random sequences aimed at spectral shaping of UWB signals. In [30], different TH codes are implemented and their PSD's have been compared. It is also suggested that more the number of chips per frame and longer the period of the TH sequence the power spread along the frequency spectrum is smoother [30]. In [24], a very interesting approach is used to design a TH code that can produce a notch at a desired frequency in the UWB spectrum. In our research we have implemented and tested the code proposed in [24].

c) Multiband Techniques

A lot of research has been done on the multiband techniques [31] [32]. In this method the UWB spectrum is divided into smaller bands. These bands are then used so that interference with other systems is avoided.

CHAPTER 5

SIMULATION AND RESULTS

5.1 System Model

Simulation model for the UWB system, IEEE 802.11a WLAN system and coexistence system are described below.

5.1.1 UWB Model

The model for UWB TH-IR transceiver used in this project is same as that explained in [33]. Pulses of very short duration are used to transmit data without a carrier. The transmission is in a train of pulses and the position of each pulse is according to a TH code to reduce the spectral peaks. A single pulse detection per frame is used. This means that the symbol time is divided into several frames and each frame contains one pulse from each user in the system. In our UWB system, for simplicity the number of bits per symbol is kept as one. The duration of the frame depends on the pulse repetition period (PRP) which gives the number of chip intervals per frame. The PRP also determines the number of users that can be accommodated without much interference to each other. PPM is the default modulation technique used and is later compared to BPM and OOK. In PPM, the pulses are shifted from their position to the left or right depending on whether a zero or one is being transmitted. The time shift of the pulses is determined by the modulation coefficient which is constant for all users.

The expression for the transmitted signal of the kth user for UWB TH-IR as given in [10] is

$$S_{tr}^{(k)}(u,t^{(k)}) = \sum_{j=-\infty}^{\infty} \omega_{tr}(t^{(k)} - jT_f - c_j^{(k)}(u)T_c - d_j^{(k)}(u)) \tag{5.1}$$

Where, ω_{tr} is the monopulse, T_f is the frame time, T_c is the chip interval, $c_j^{(k)}$ *(u)* is the pseudo random code, $d_j^{(k)}$ *(u)* is the modulation coefficient, and the subscript j represents the jth monopulse, and *u* represents the uth pulse.

At the receiver we use single pulse detection per frame. The signal at the receiver is given by the addition of the signals through all the paths (taps) and the signals from all the users. AWGN (additive white Gaussian noise) is added at the receiver as shown in Figure 24.

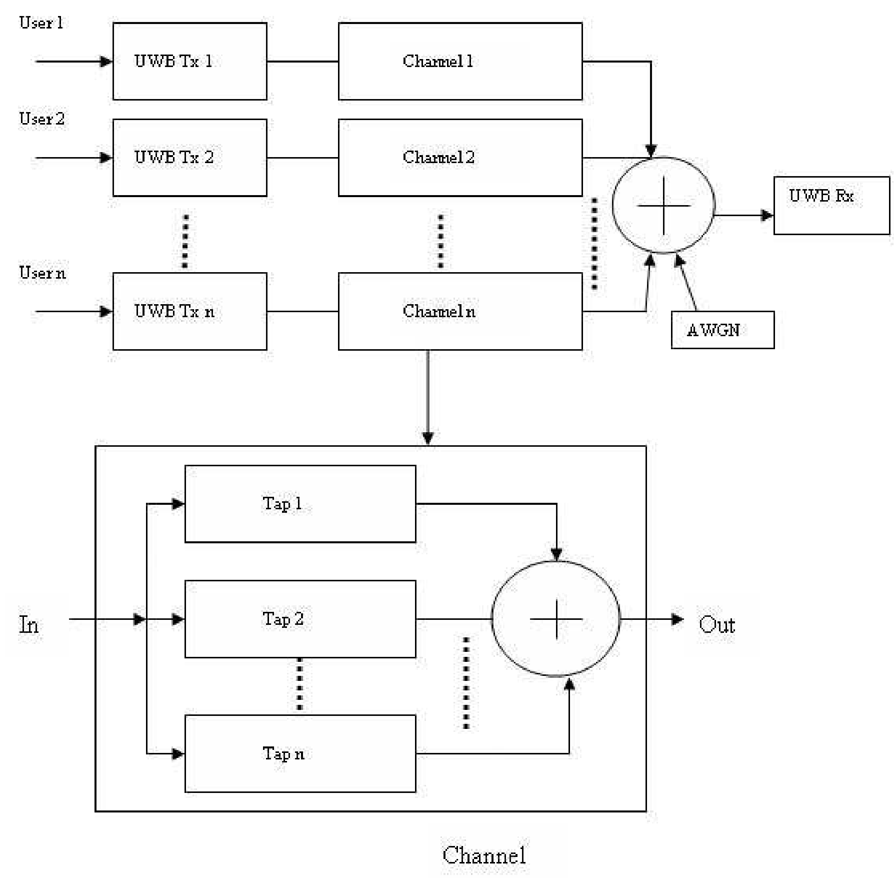

Figure 24. UWB System Model

A unique PN code is assigned to each user. For Direct Sequence Spread Spectrum UWB, each incoming bit is spread by using a pseudo random spreading sequence. The length of the spreading sequence is determined by the number of pulses per bit that we want. Here for comparison purposes the number of pulses per bit has been maintained to be same for the Time Hopped Spread Spectrum and the Direct Sequence Spread Spectrum.

5.1.2 Wireless LAN Model

The WLAN model used is the IEEE 802.11a OFDM WLAN model given in [34]. The size of the packet and the number of packets for WLAN system is variable. AWGN channel and exponential decay channel are used for the WLAN system. The channel is assumed static over the duration of one packet. The major interference to WLAN systems (in addition to to multiple UWB users) is introduced by the shadowing and channel impulse response and hence these are the two parameters that have been considered in the channel model. The WLAN model can use different modulation techniques.

5.1.3 Coexistence Model

The UWB transmitters are assumed to be in very close proximity to the 802.11a stations (STAs) and away from the Access Point (AP). So all the interference that is considered here is the downlink interference caused to the received 802.11a signal. The path loss model for the 802.11a OFDM WLAN is given by.

$$P_r(d) = P_r(d_{ref})\ (d/d_{ref})^{-K} \tag{5.2}$$

Where,
$P_r(d)$ is the power at distance d
$P_r(d_{ref})$ is the power at distance d_{ref}
K is the path loss index

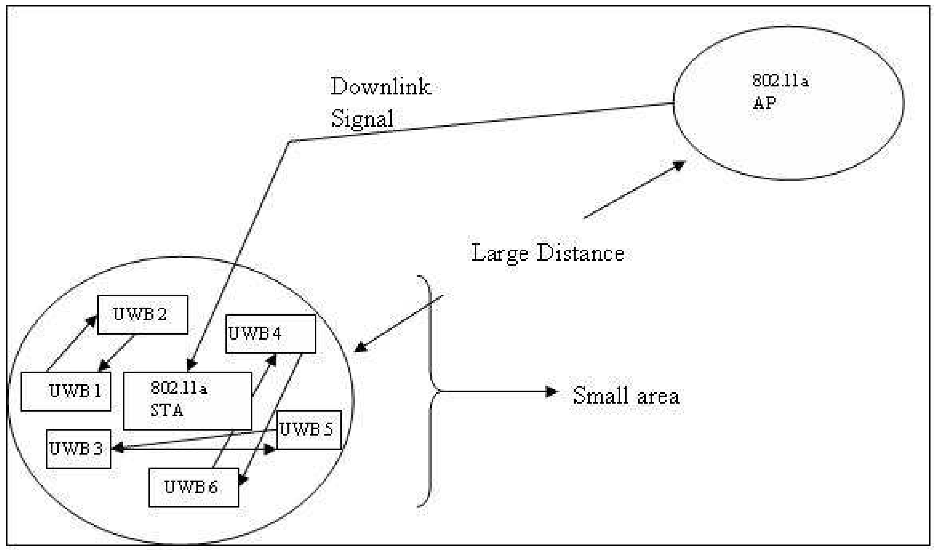

Figure 25. UWB and IEEE 802.11a Colocation Model

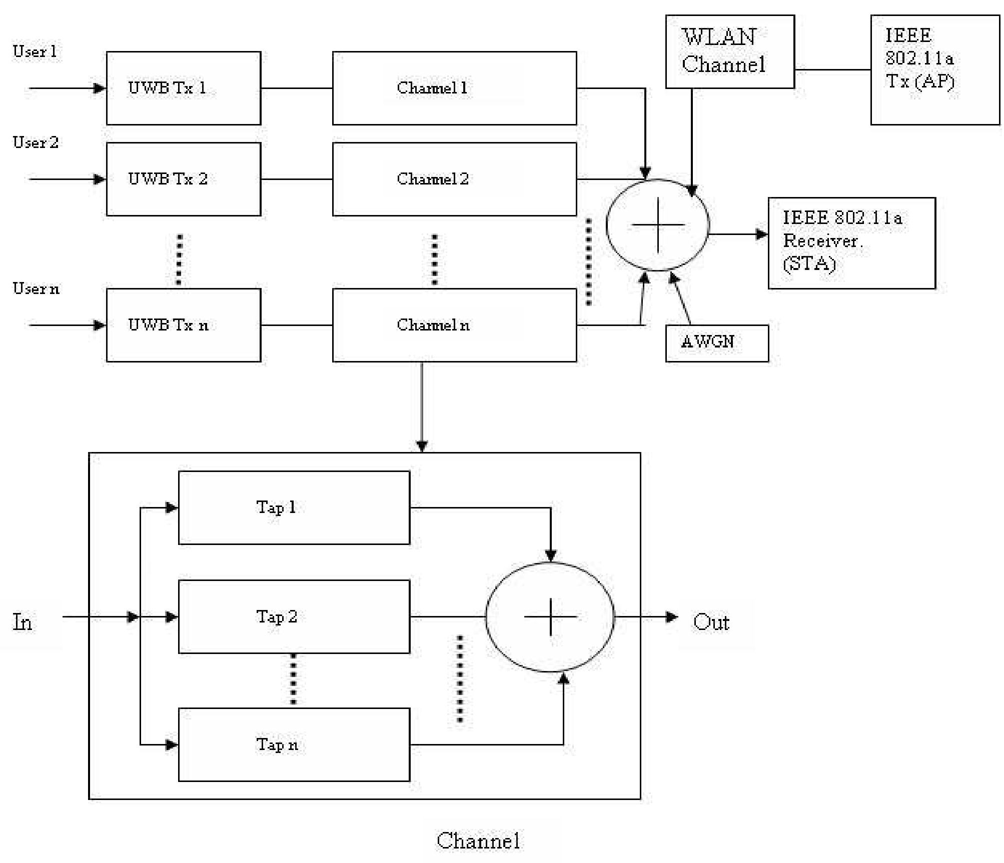

Figure 26. UWB and IEEE 802.11a Coexistence System Model

The path loss exponent for 802.11a is considered to be 3.3 [18]. However since the UWB transmitters are assumed to be in very close proximity to the STAs, the path loss of the UWB transmitters at the STAs is negligible. The received signal at the 802.11a STA is given by

$$y_n = (h_n * x_n) + w_n + u_n \tag{5.3}$$

where

y_n is the received downlink signal at the 802.11a STA

x_n is the transmitted downlink signal

h_n is the impulse response of the channel, w_n is AWGN

u_n is the combined interference of all the UWB users.

The UWB signal is filtered for the 5.21 – 5.23 GHz frequency band and frequency aligned before addition.

5.2 Simulation Parameters

Simulation parameters for the UWB and the IEEE 802.11a WLAN models are given below.

5.2.1 UWB Parameters

The simulation was done using Matlab. A UWB transmission system with a variable pulse width is considered. The data rate is 30 Mbps. The SNR is kept at 10 dB. The default PRP is 100 except when otherwise specified. The length of spreading sequence varies from 28 to 200. The default modulation used is BPM. The default spreading scheme used is TH – IR exept when specified otherwise.The number of pulses per bit is kept constant for the DSSS and TH-IR systems. The default pulse shape is the fourth derivative of Gaussian pulse and the default pulse width is 96.15 ps except when specified otherwise. There are 7 simulataneous UWB users in the immediate vicinity of the WLAN STA. For no multipath scenario a single tap channel is used whereas for the dense multipath scenario 30 tap channel is used. The channel model considered here is the IEEE 802.15.3 indoor wireless channel model given in [35].

5.2.2 WLAN Parameters

The IEEE 80.11a OFDM WLAN system used is operating at 5 GHz. It supports different "data payload communication capability" by using different modulation schemes and coding rates [18]. We use the 802.11a system operating at 24 Mbps. The signal to noise ratio is kept at 10 dB. 16 QAM modulation is used with ½ rate coding for all the simulations. In each run 100 packets were sent with each packet containing 100 bytes. The results were averaged based on 10 simulation runs.

5.3 Effect of UWB Parameters on WLAN Performance

The following section gives the results for the comparison of various UWB parameters with respect to the interference caused to the IEEE 802.11a system.

5.3.1 Comparison of Pulse Shapes

Gaussian monopulse and the fourth derivative of Gaussian pulse are the pulse shapes (PS) considered here. The pulse width is 0.2 ns. The results shown in Figure 27, Figure 28, Figure 29 and Figure 30 suggest that for a single tap channel the higher derivative of Gaussian pulse performs better than the Gaussian monopulse. The throughput and BER performance of an IEEE 802.11a WLAN system with interference from 7 simultaneous UWB systems using fourth derivative of Gaussian pulse (in the absence of multipath) is better for smaller distances as compared to that of an IEEE 802.11a system with interference from 7 UWB users using the Gaussian monopulse. Also with increase in the number of UWB interferers the throughput and BER performances of an IEEE 802.11a system with interference from 7 UWB users using fourth derivative of Gaussian pulse is better when compared to the IEEE 802.11a system with interference from 7 UWB users using Gaussian monopulse.This is because the PSD of fourth derivative of Gaussian pulse is lower than the Gaussian pulse. Our results shown in Figure 31 , Figure 32, Figure 33, and Figure 34 suggest that this is true even in the presence of dense multipath. However, in the presence of dense multipath the advantage offered by the fourth derivative over the Gaussian monopulse is marginal for a large number of UWB interferers. A report [37] suggests that BER performance of UWB systems using higher derivative of Gaussian pulses may be worse than that of a lower derivative. Here we are only concerned about interference caused to other systems (WLAN) and so higher derivative of Gaussian pulse is the pulse shape of choice but in an actual scenario the selection has to be based on the number of UWB interferers, the target range of operation, multipath scenario and the performance of UWB receiver itself.

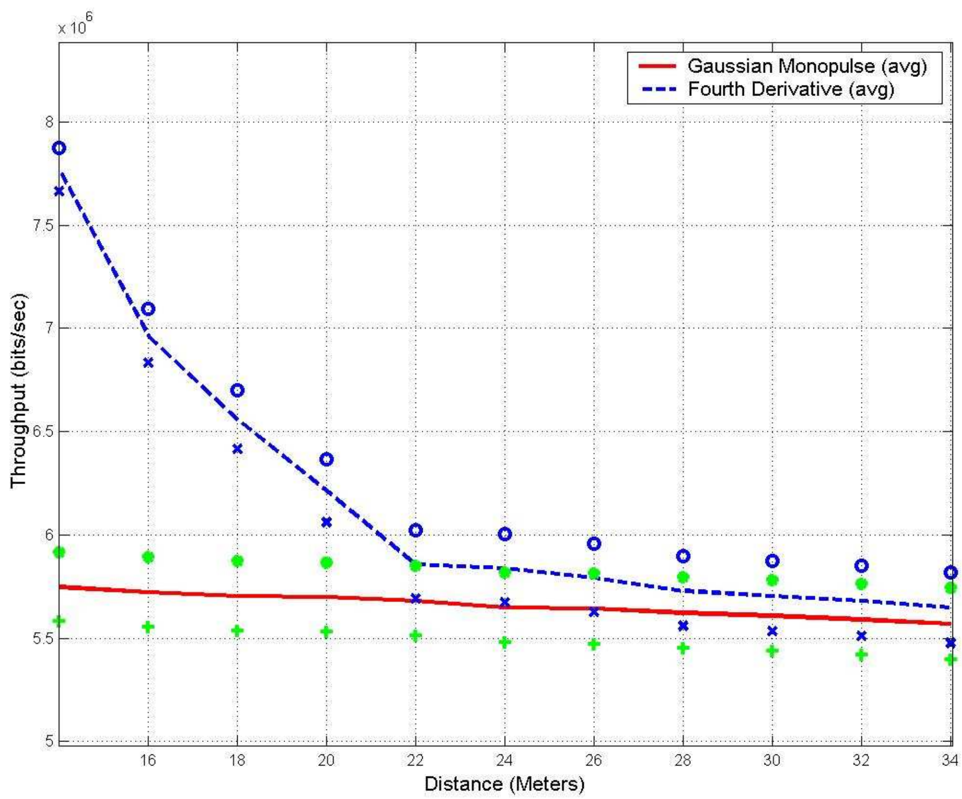

Figure 27. Throughput vs Distance (PS, 7 UWB Interferers, No Multipath (NM))

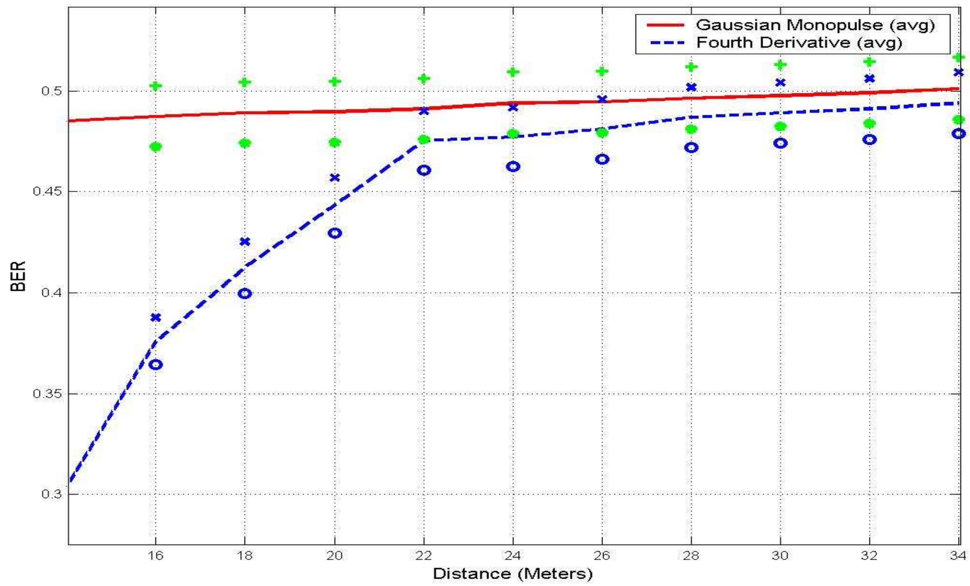

Figure 28. BER vs Distance (PS, 7 UWB Interferers, NM)

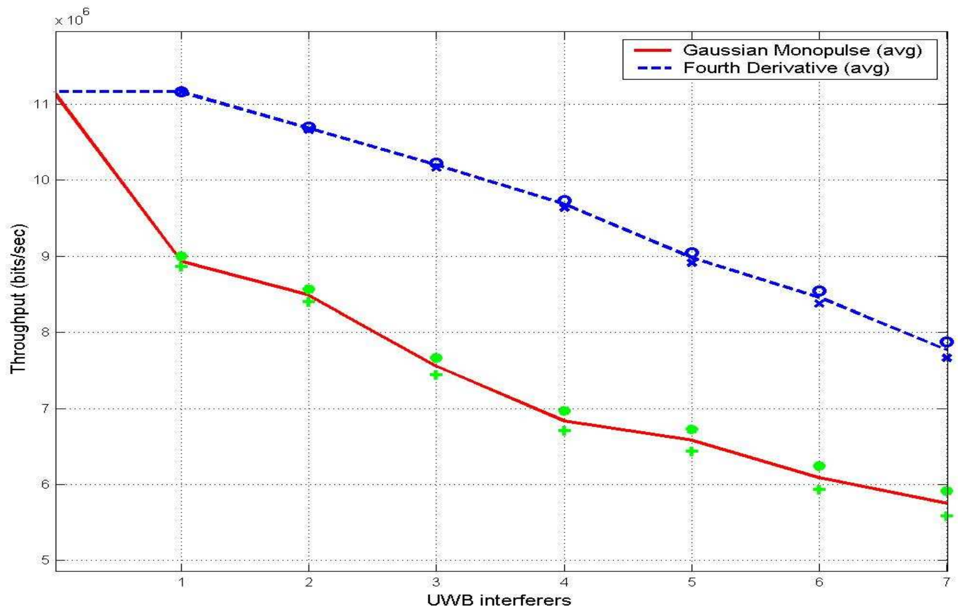

Figure 29. Throughput vs UWB Interferers (PS, STA to AP – 14 m, NM)

Note: '*' and '+' represent the maximum and minimum values for the throughput and minimum and maximum values for the BER. Similarly, 'o' and 'x' represent the maximum and minimum values for throughput and minimum and maximum values for BER as well.

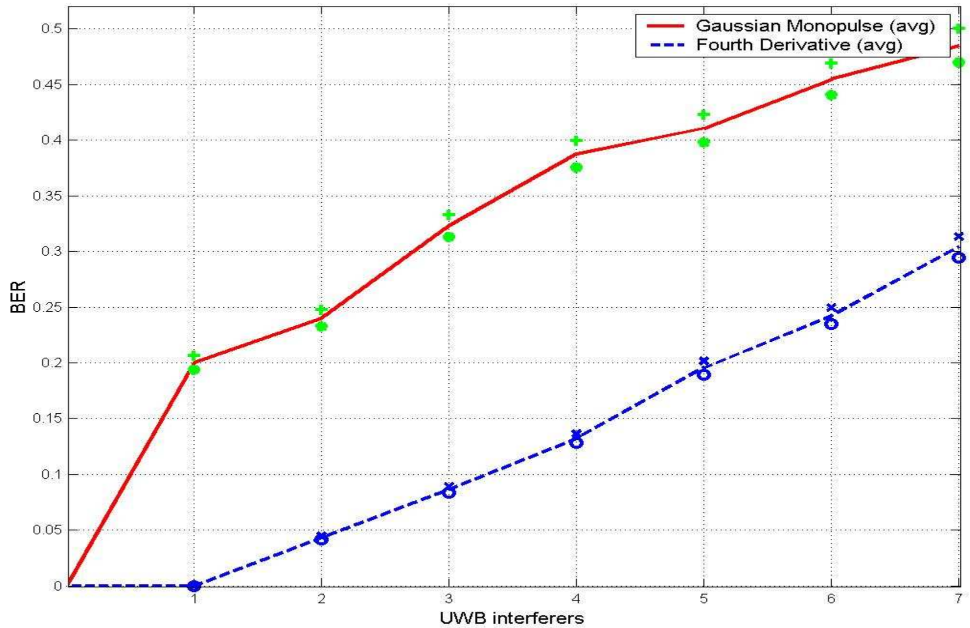

Figure 30. BER vs UWB Interferers (PS, STA to AP – 14 m, NM)

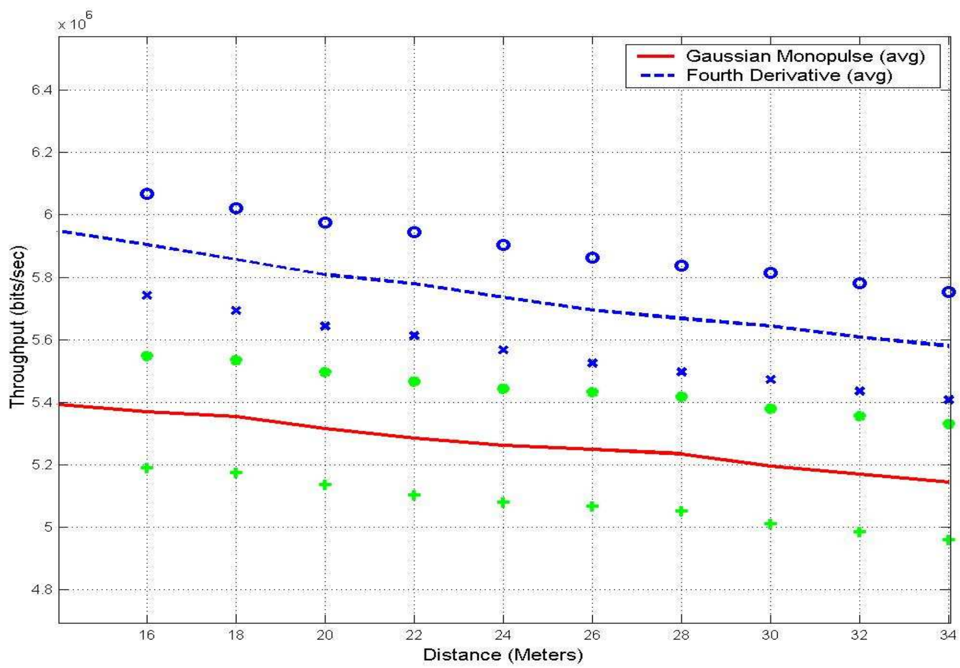

Figure 31. Throughput vs Distance (PS, 7 UWB Interferers, 30 Taps)

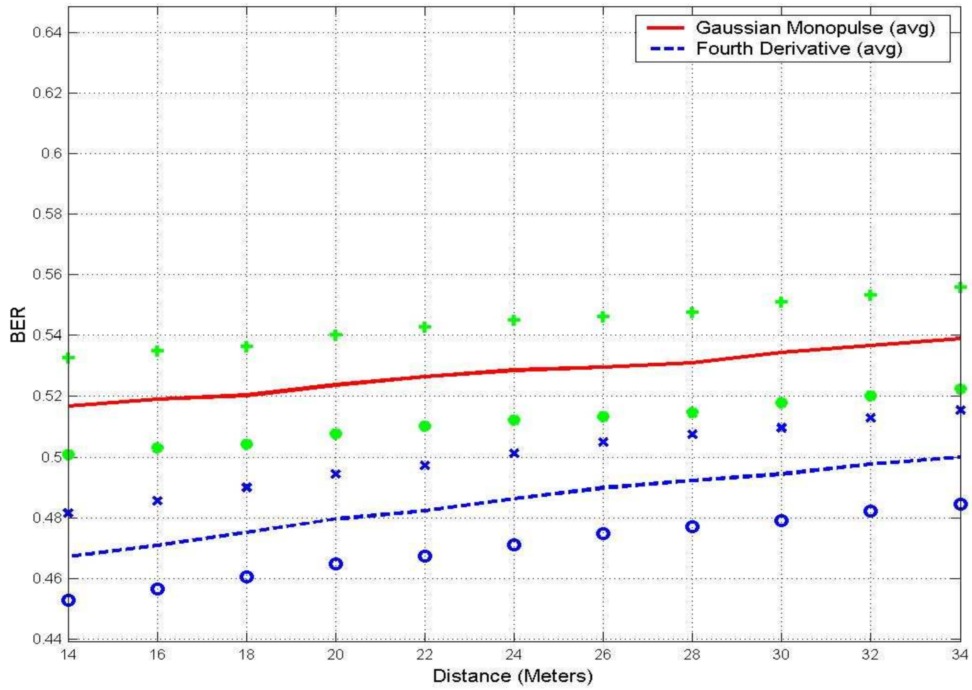

Figure 32. BER vs Distance (PS, 7 UWB Interferers, 30 Taps)

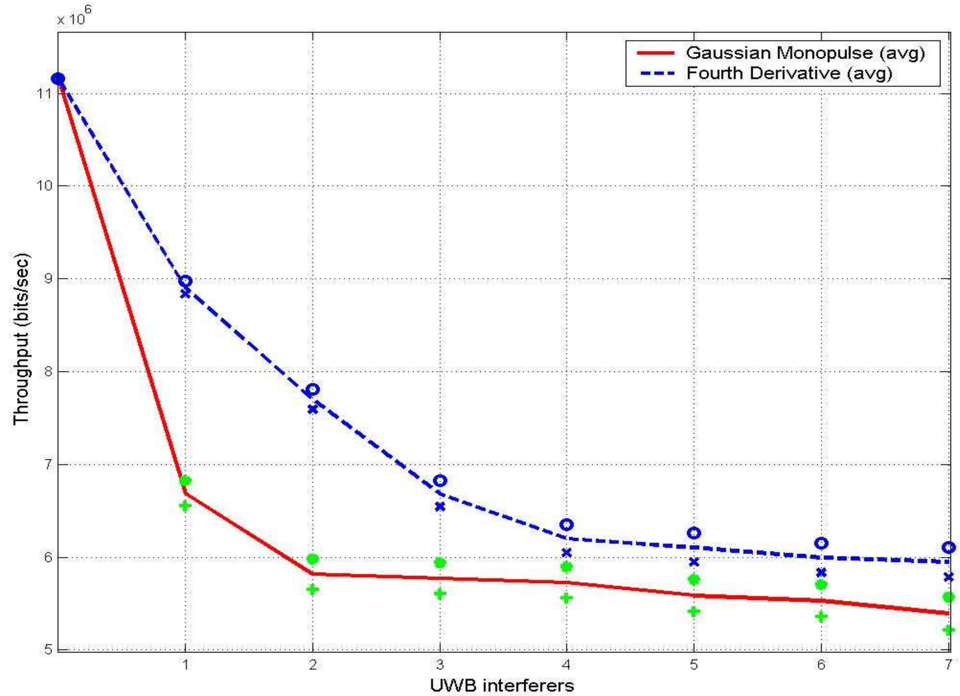

Figure 33. Throughput vs UWB Interferers (PS, STA to AP - 14 m, 30 Taps)

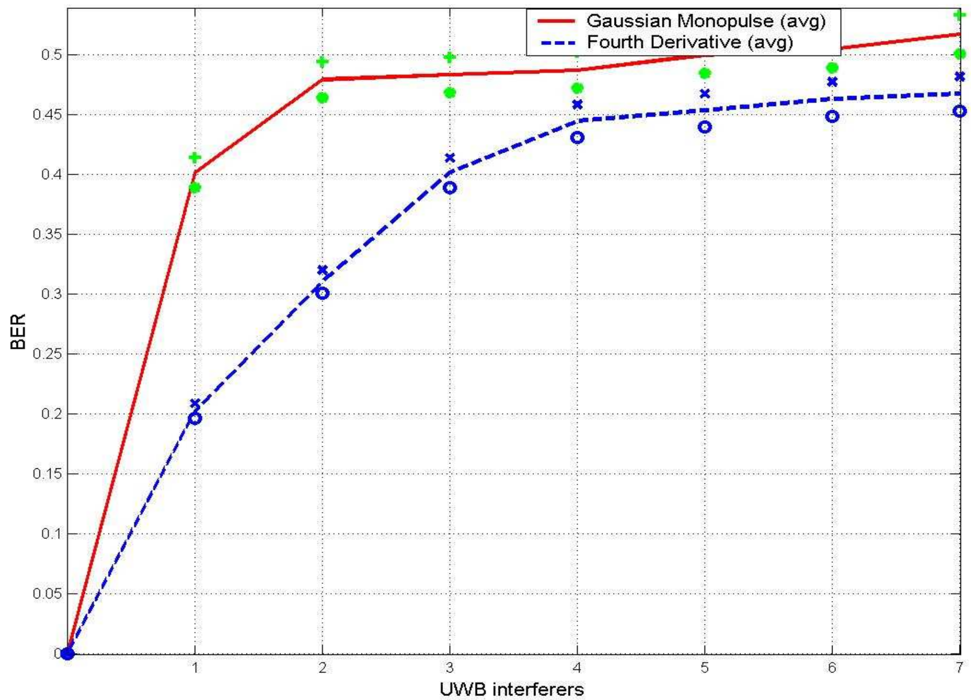

Figure 34. BER vs UWB Interferers (PS, STA to AP – 14 m, 30 Taps)

5.3.2 Comparison of Pulse Widths

Two pulse widths (PW) of 0.2 ns and 96.15 ps are considered here. We have considered the fourth derivative of the Gaussian pulse as the pulse shape. The results shown in Figure 35, Figure 36, Figure 37, and Figure 38 suggest that for a single tap channel the narrow pulse (96.15 ps) performs better than the wider pulse (0.2 ns). The throughput and BER performances of an IEEE 802.11a WLAN system with interference from 7 simultaneous UWB systems using narrow pulse (in the absence of multipath) are better when compared to that of an IEEE 802.11a WLAN system with interference from 7 UWB users using wider pulse. Also with increase in the number of UWB interferers the throughput and BER performances of an IEEE 802.11a system with interference from 7 UWB users using narrower pulse are better when compared to that of IEEE 802.11a WLAN system with interference from 7 UWB users using narrow pulse. This is because the center frequency of the PSD of narrower pulse moves farther away from the operating band (5 GHz) of IEEE 802.11a and therefore has less interference power in the frequency band of interest than the wider pulse. Our results in Figure 39, Figure 40, Figure 41, and Figure 42 suggest that in the presence of multipath the performance of IEEE 802.11a system with interference from the narrower pulse width is better than that of the IEEE 802.11a system with interference from the wider pulse witdh. However the advantage offered by the narrow pulse in terms of interference power reduction is marginal in the presence of dense multipath. This is because the effect of multipath is much more dominant and so the interference power caused by both the narrow pulse and the wide pulse increases significantly and the difference between them reduces. Here we are concerned about the performance of the WLAN system in non multipath and dense multipath scenarios but in actual scenario the choice needs to be made by including other factors such as implementation cost for generating very narrow pulses and performance of UWB receiver.

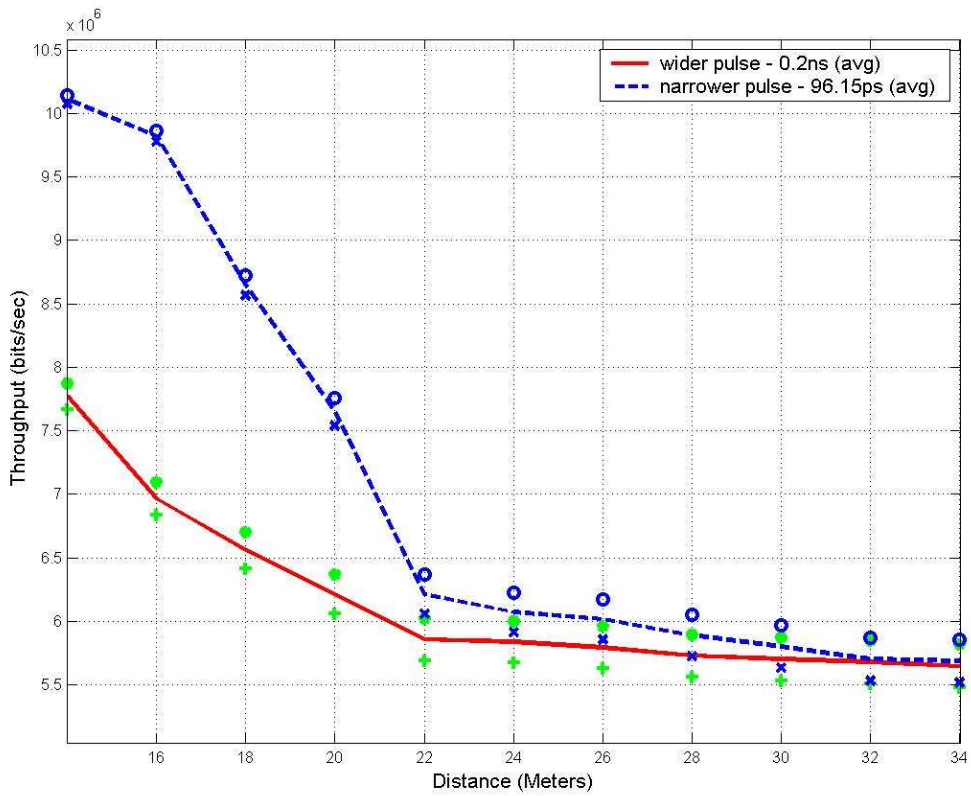

Figure 35. Throughput vs Distance (PW, 7 UWB Interferers, NM)

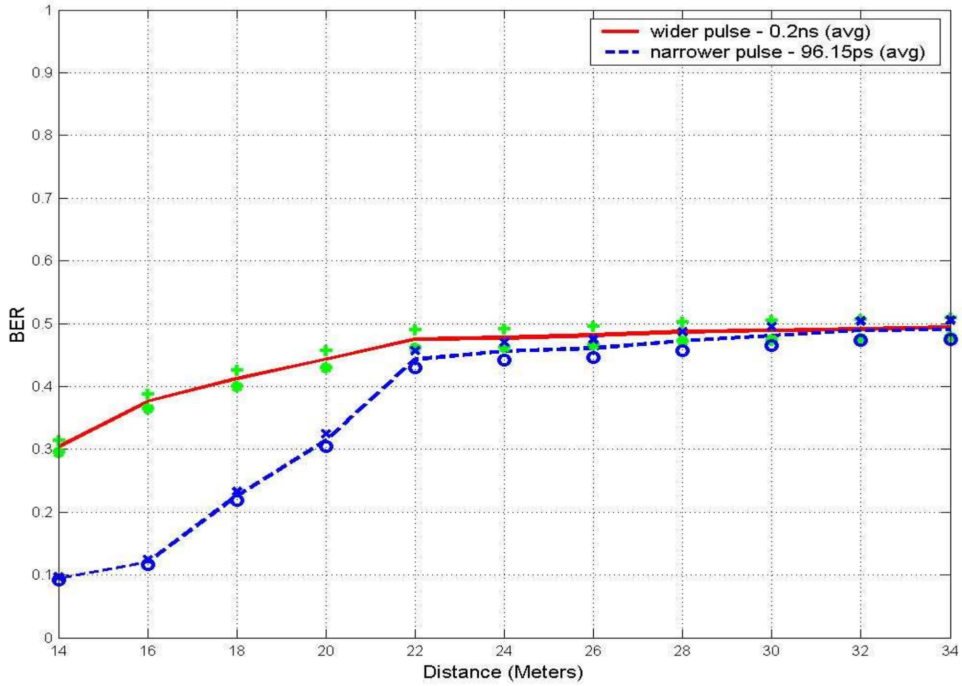

Figure 36. BER vs Distance (PW, 7 UWB Interferers, NM)

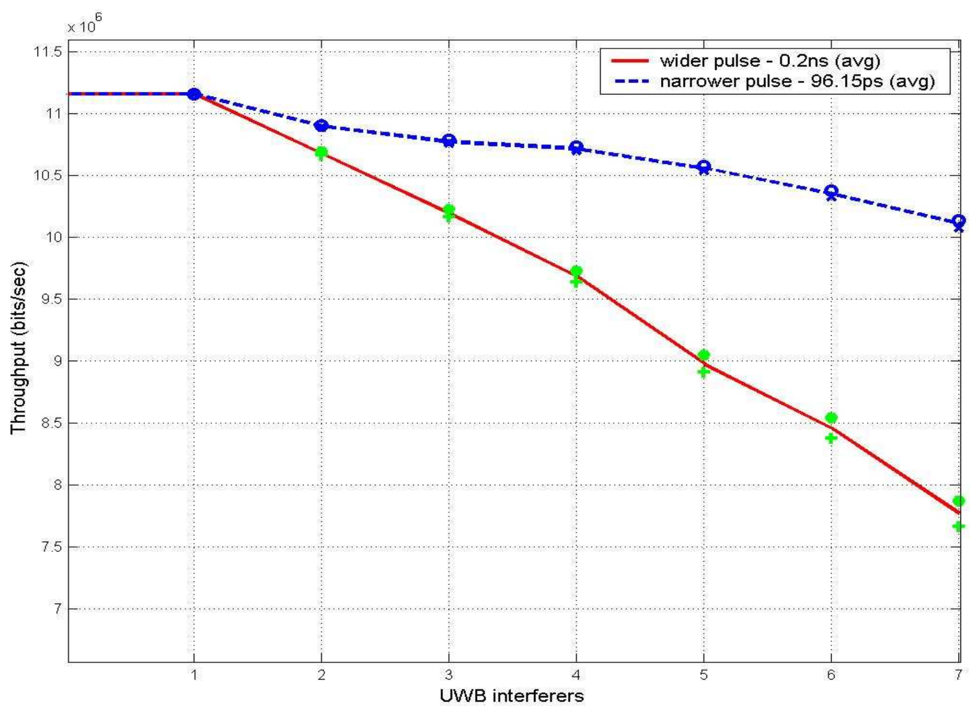

Figure 37. Throughput vs UWB Interferers (PW, STA to AP – 14 m, NM)

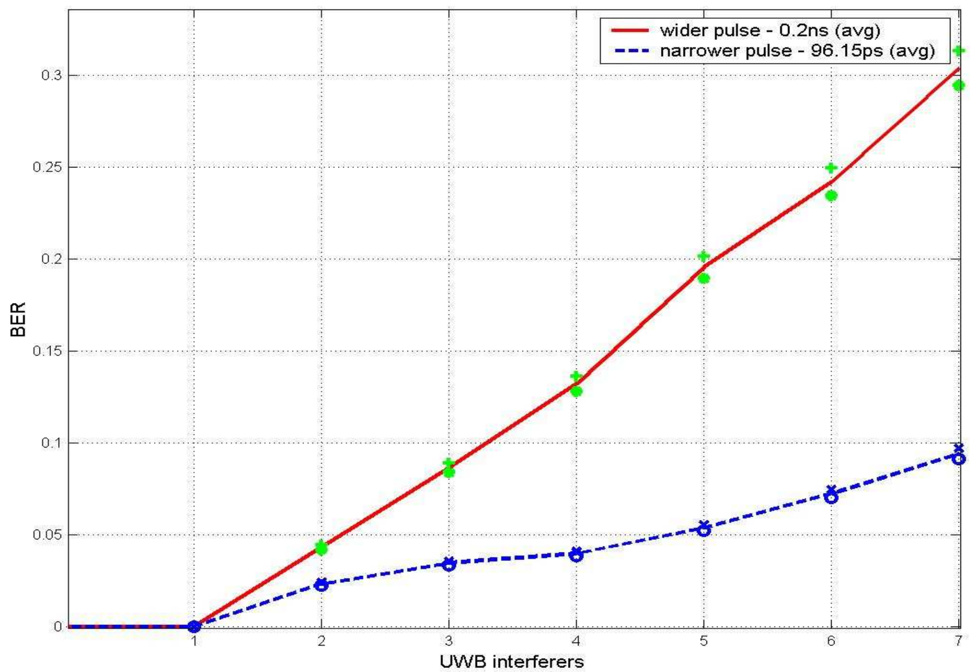

Figure 38. BER vs UWB Interferers (PW, STA to AP – 14 m, NM)

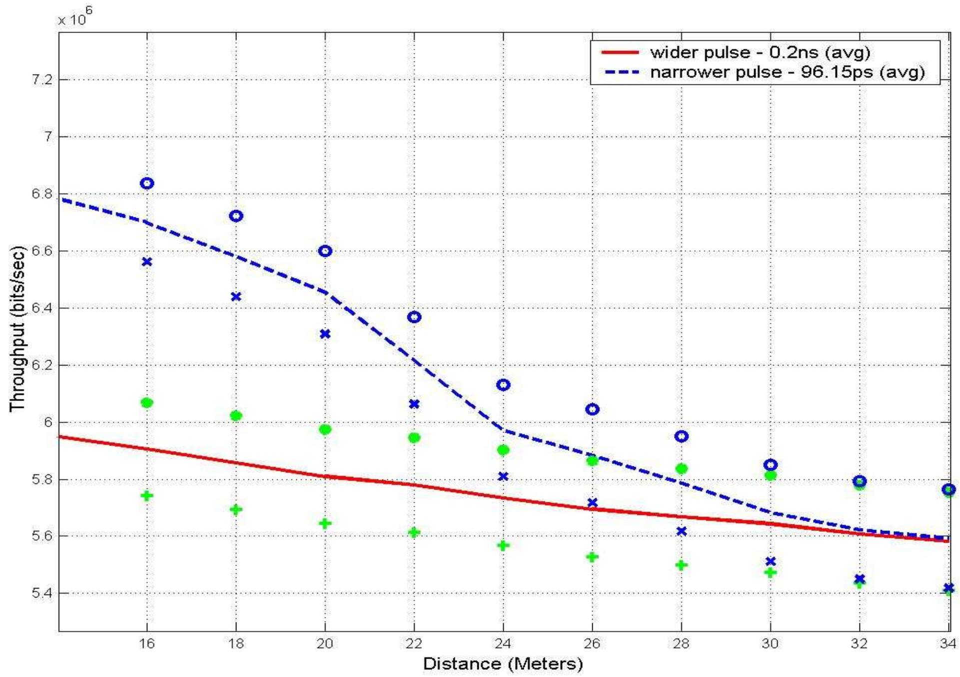

Figure 39. Throughput vs Distance (PW, 7 UWB Interferers, 30 Taps)

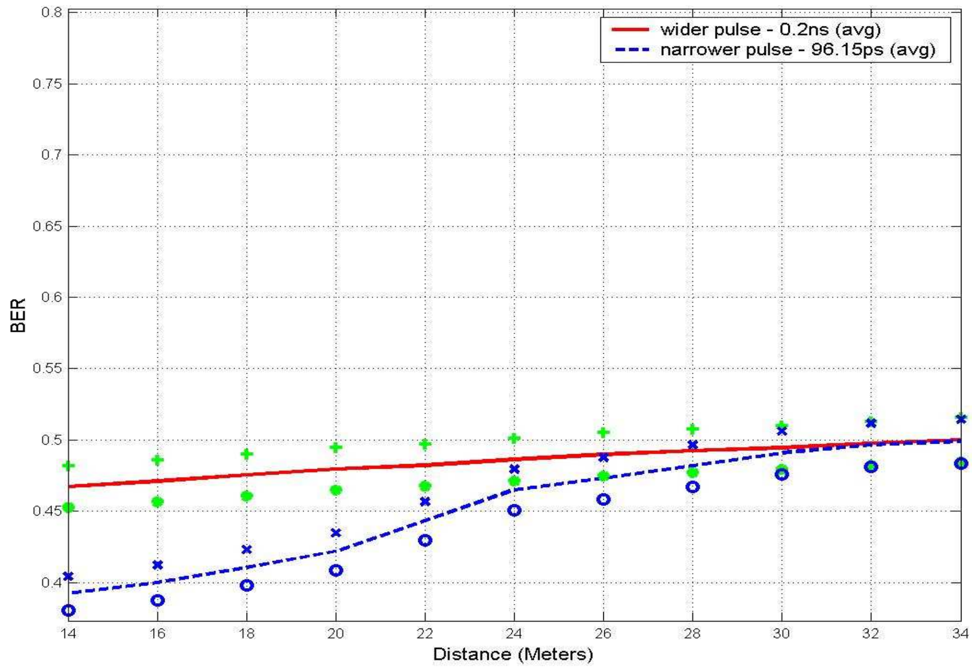

Figure 40. BER vs Distance (PW, 7 UWB Interferers, 30 Taps)

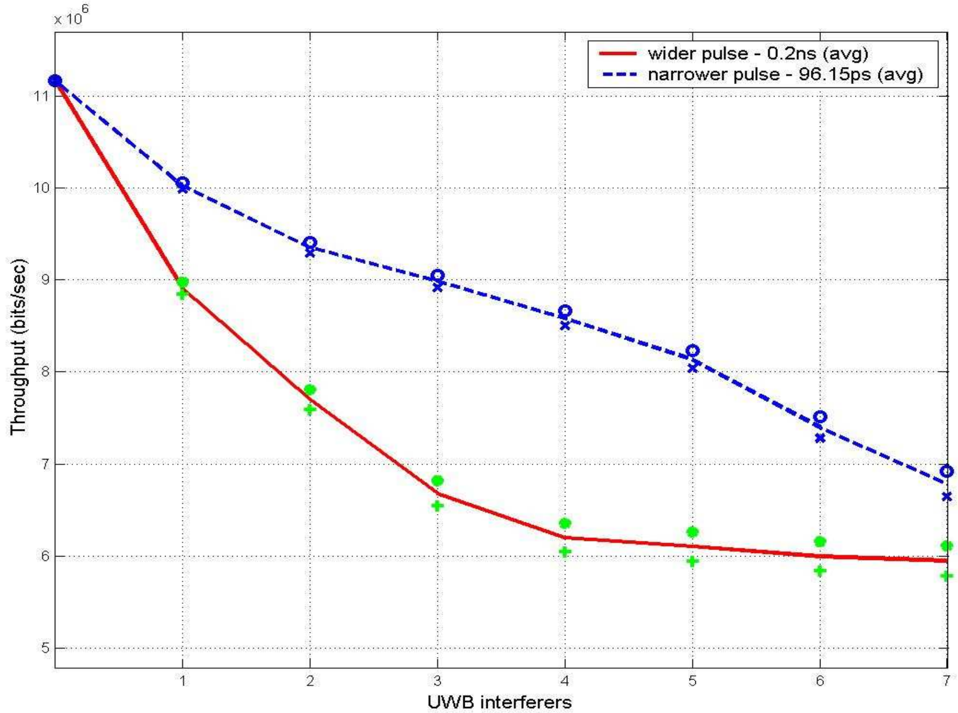

Figure 41. Throughput vs UWB Interferers (PW, STA to AP – 14 m, 30 Taps)

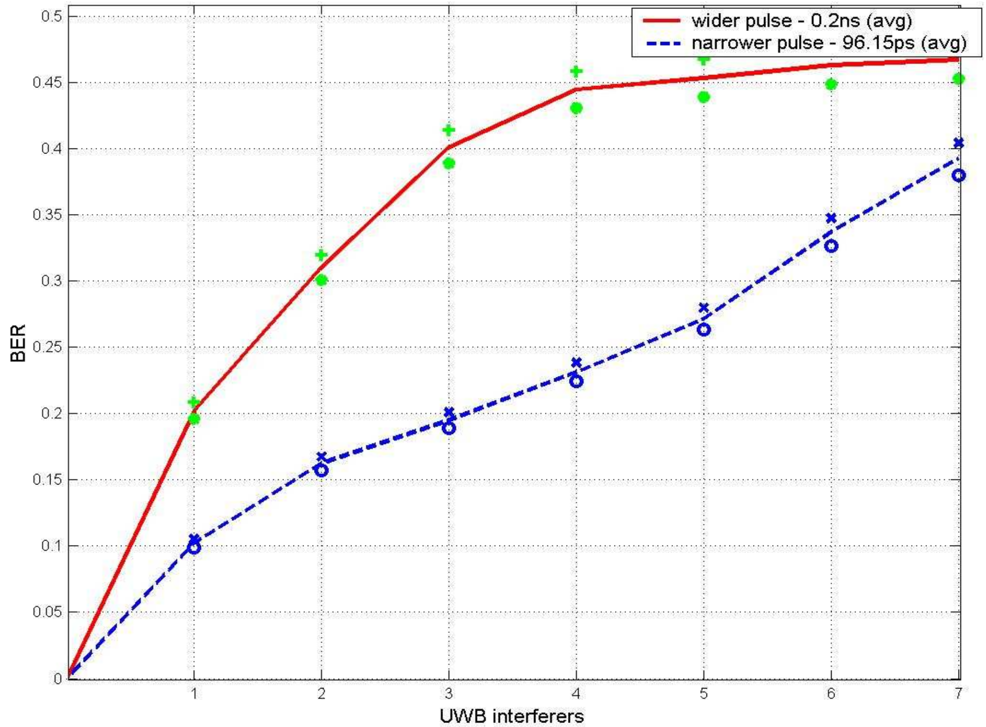

Figure 42. BER vs UWB Interferers (PW, STA to AP – 14 m, 30 Taps)

5.3.3 Comparison of PRF

A UWB TH-IR system with BPM using the fourth derivative of Gaussian pulse is considered. The results shown in Figure 43, Figure 44, Figure 45, and Figure 46 indicate that in the absence of multipath channel the throughput and BER performances of an IEEE 802.11a system with interference from 7 simultaneous UWB systems using a pulse repetition frequency higher than the narrowband receiver frequency are only marginally better when compared to that of a IEEE 802.11a system with interference from 7 simultaneous UWB systems using a pulse repetition frequency(PRF) lower than the narrowband receiver frequency. The PSD of UWB signal with low PRF is lower than that with high PRF. Inspite of this the marginal advantage is gained because when the UWB interferers have a high PRF the UWB signal is distributed uniformly along the symbol of the IEEE 802.11and produces an effect like additive white noise which can be averaged out. When the PRF is low then the distribution is not uniform and this leads to errors at the IEEE 802.11a receiver. This is in conformance with the anaysis done in [14]. However, from the results in Figure 47, Figure 48, Figure 49, and Figure 50 it is clear that in the presence of multipath the throughput and BER performances of an IEEE 802.11a system with interference from 7 simultaneous UWB systems using low PRF are slightly better than the throughput and BER performances of an IEEE 802.11a system with interference from 7 simultaneous UWB systems using high PRF. This is because due to multipath the lower PRF UWB interference also gets uniformly distributed and becomes noise like. Thus the advantage that high PRF offers is nullified in the presence of multipath. The choice of PRF needs to be made based on the multipath model and the UWB receiver performance.

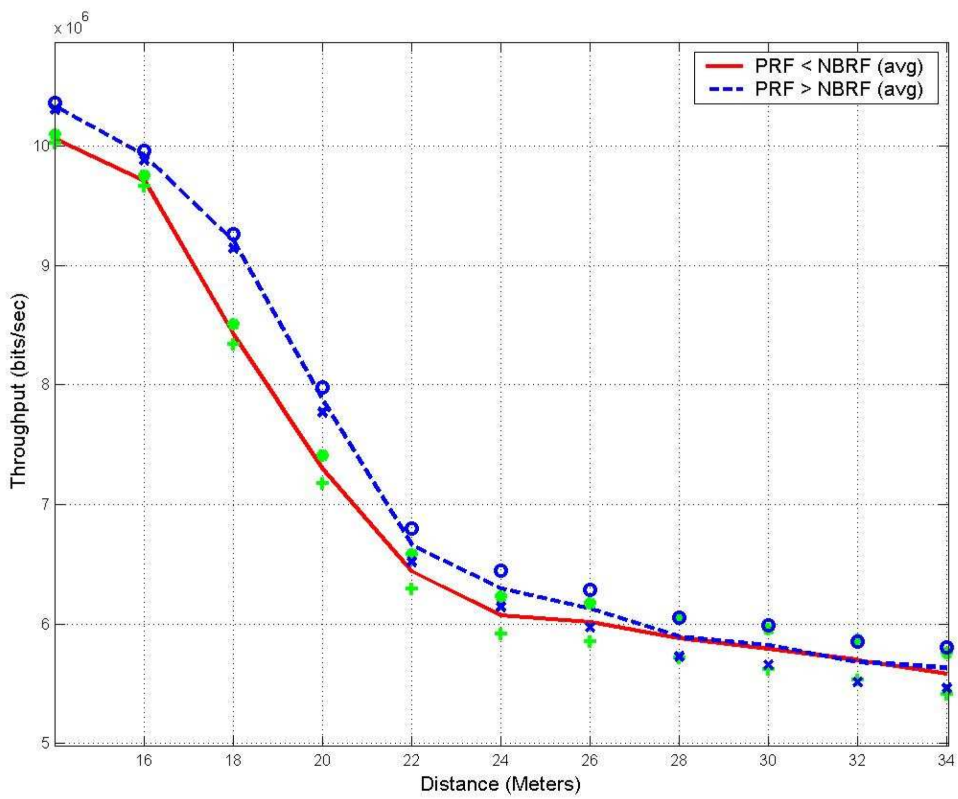

Figure 43. Throughput vs Distance (PRF, 7 UWB Inteferers, NM)

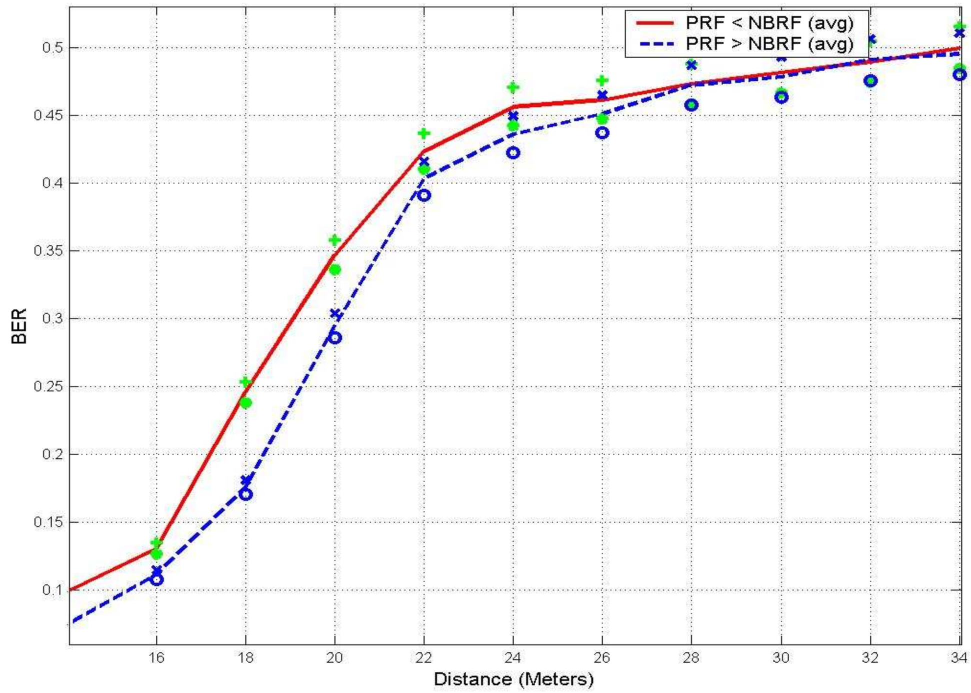

Figure 44. BER vs Distance (PRF, 7 UWB Interferers, NM)

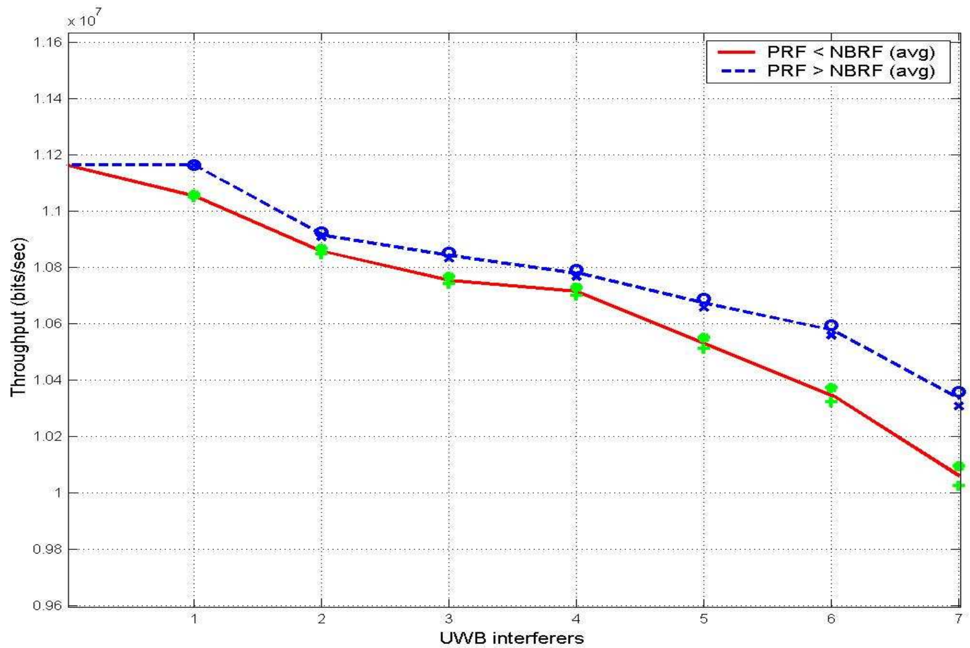

Figure 45. Throughput vs UWB Interferers (PRF, STA to AP – 14 m, NM)

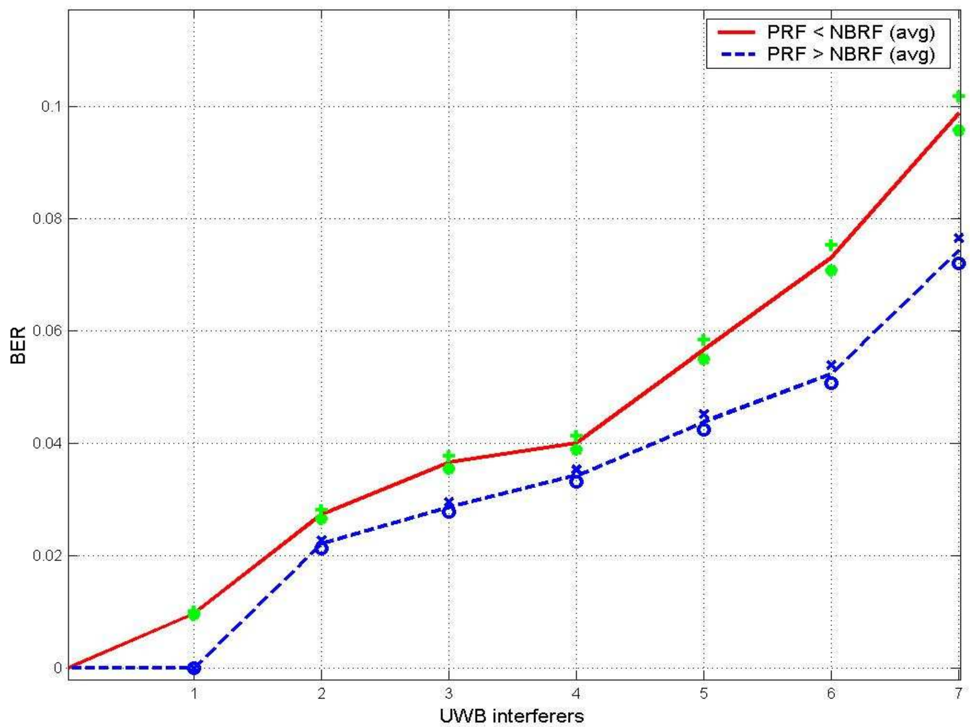

Figure 46. BER vs UWB interferers (PRF, STA to AP – 14 m, NM)

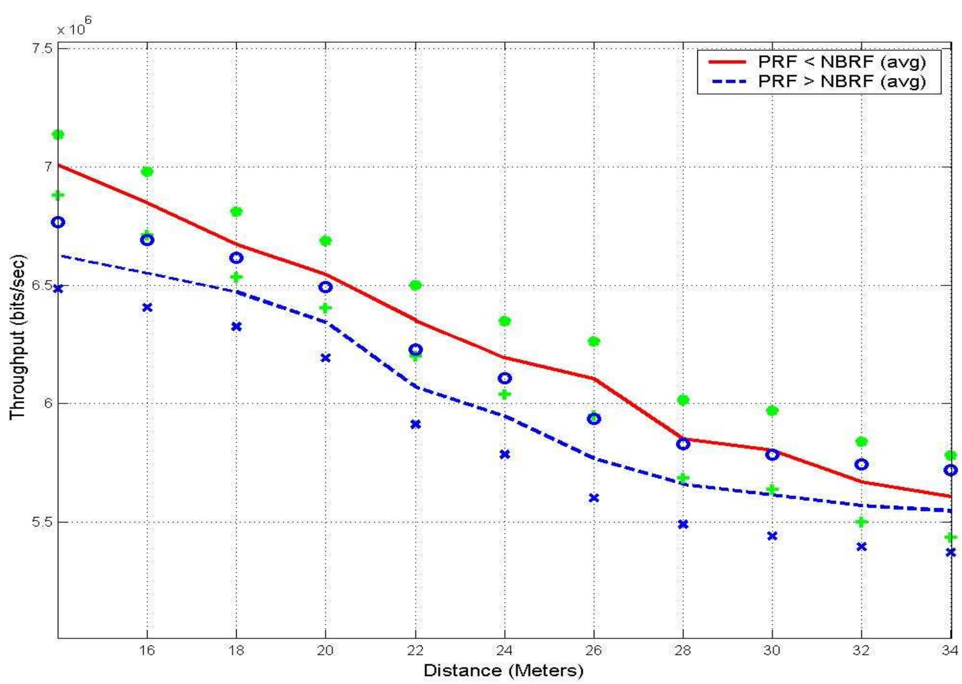

Figure 47. Throughput vs Distance (PRF, 7 UWB Interferers, 30 Taps)

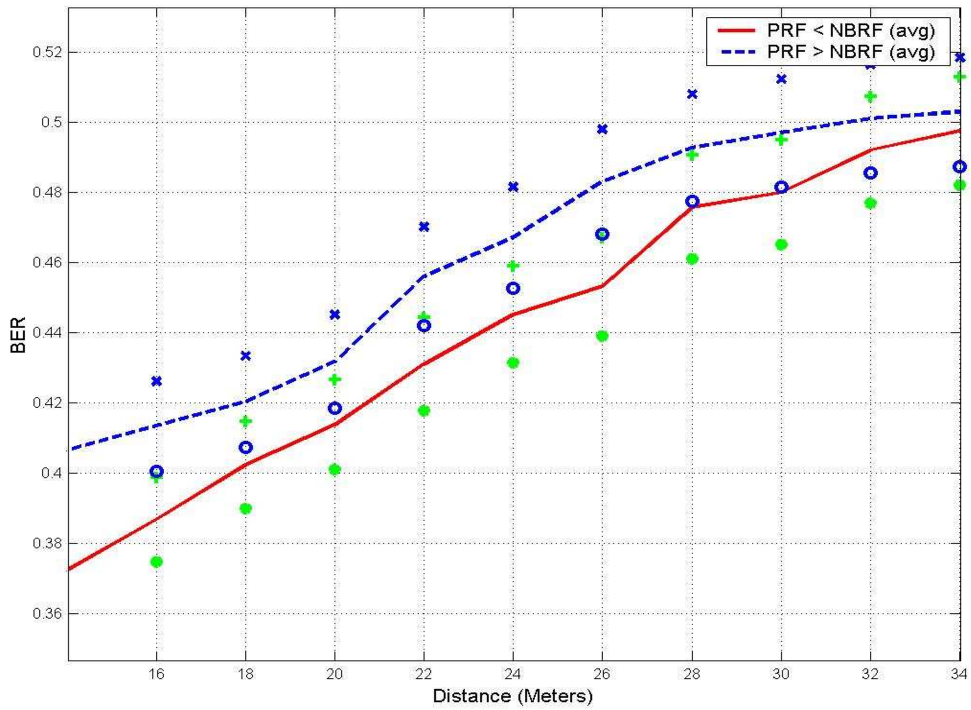

Figure 48. BER vs Distance (PRF, 7 UWB Interferers, 30 Taps)

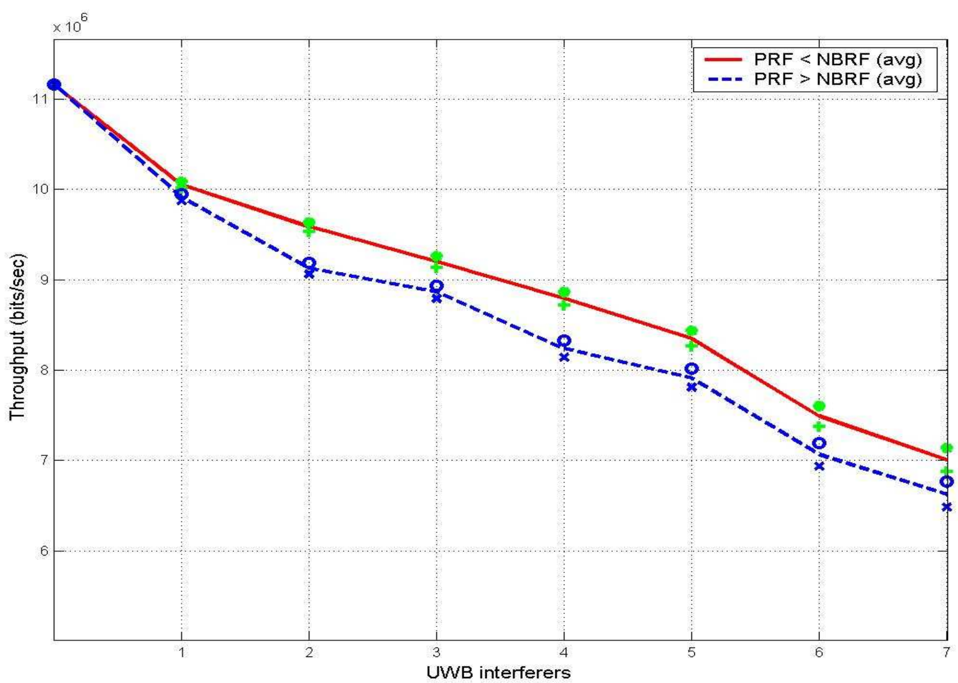

Figure 49. Throughput vs UWB Interferers (PRF, STA to AP – 14 m, 30 Taps)

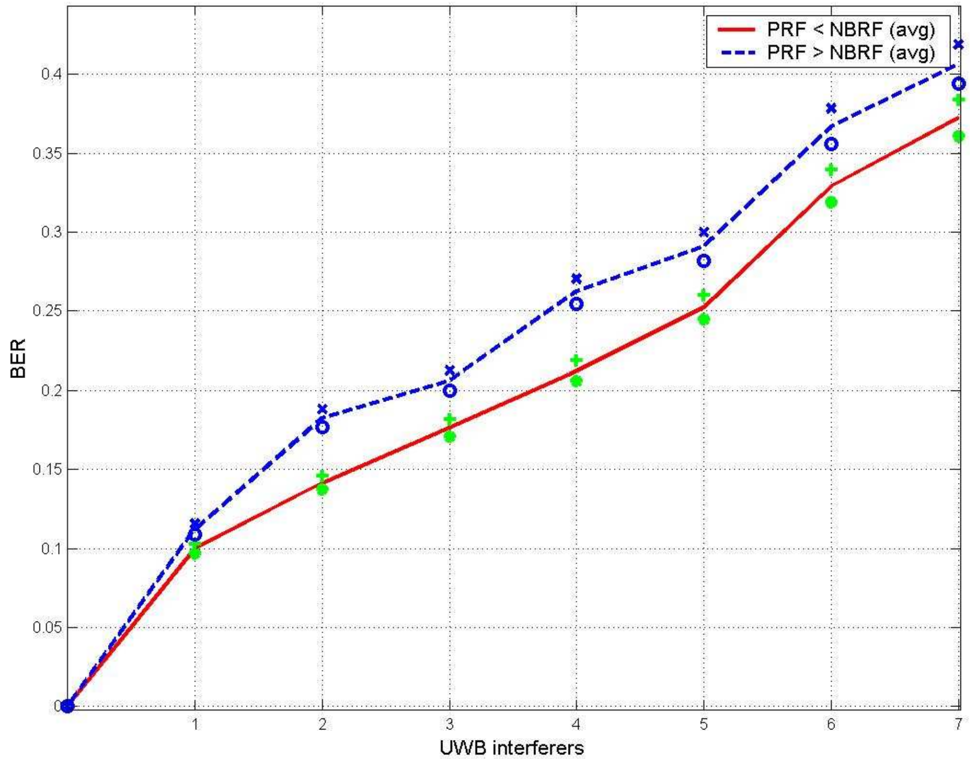

Figure 50. BER vs UWB Interferers (PRF, STA to AP – 14 m, 30 Taps)

5.3.4 Comparison of Spreading Techniques

Two spreading techniques (ST) namely DSSS and TH have been compared here.The results shown in Figure 51, Figure 52, Figure 53, and Figure 54 are for a single tap channel using BPM modulation for both the TH-IR and the DSSS UWB systems. It has been observed in [25], that the DSSS system has a slightly lower PSD than the TH-IR. Our results show that (in absence of multipath) throughput and BER performances of an IEEE 802.11a system with interference from 7 UWB users using DSSS are slightly better than that of an IEEE 802.11a WLAN system with interference from 7 simultaneous UWB systems using TH-IR. This is due to the fact that in the absence of multipath, the PSD of a UWB DSSS system is much smoother than the PSD of a UWB TH-IR system. The results in Figure 55, Figure 56, Figure 57, and Figure 58 are for a 30 tap channel using BPM modulation for

DSSS and TH-IR UWB systems. It has been suggested in [23] that the BER performance of the UWB DSSS degrades in the presence of multipath. However we are concerned about the effect on the BER of the IEEE 802.11a OFDM WLAN system. Our results indicate that for an IEEE 802.11a OFDM WLAN system with interference from 7 simultaneous UWB DSSS systems (in the presence of multipath) the throughput and BER performances are slightly worse as compared to the throughput and BER performances of an IEEE 802.11a system with interference from 7 UWB users using TH-IR. This is because in the presence of multipath the PSD of DSSS does not remain smooth and consists of spectral peaks introduced due to multipath. However, comparatively the PSD of TH-IR does not degrade as much because of the randomness in pulse position introduced by the TH code. As the number of taps in the multipath channel increase the periodicity introduced in DSSS increases rapidly compared to TH-IR and so the PSD of TH-IR is better for dense multipath environments.

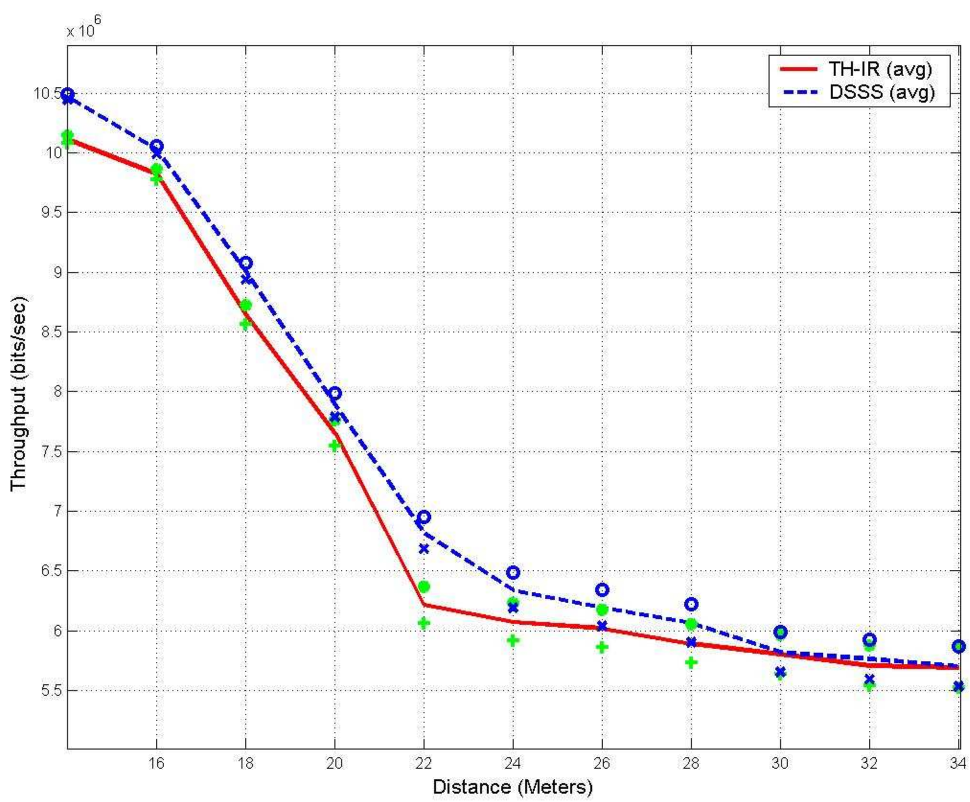

Figure 51. Throughput vs Distance (ST, 7 UWB Interferers, NM)

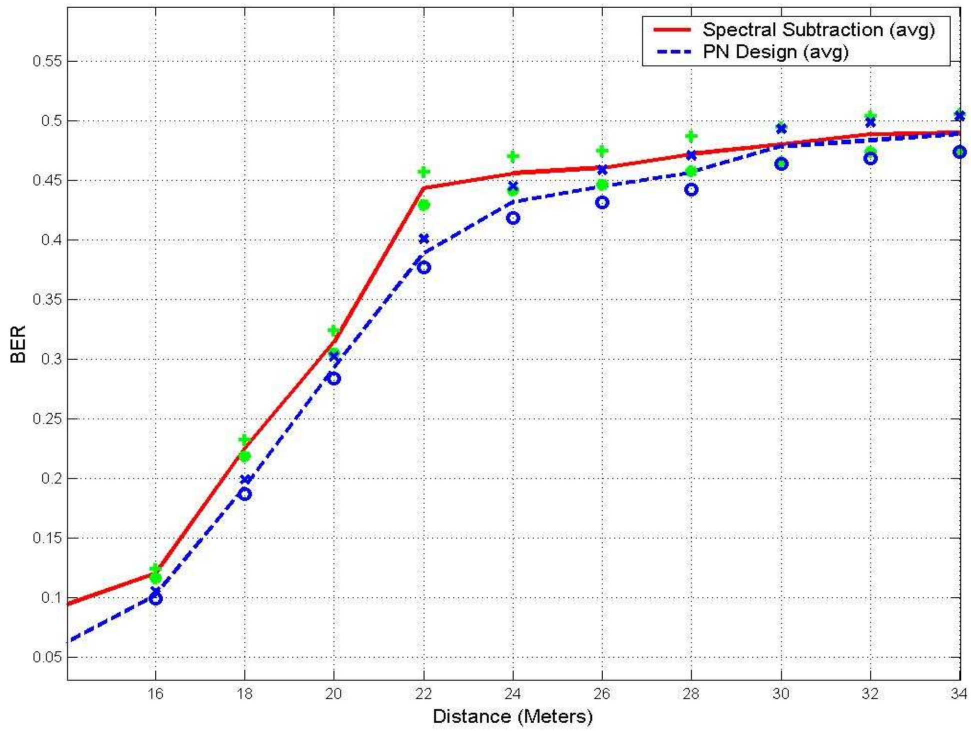

Figure 52. BER vs Distance (ST, 7 UWB Interferers, NM)

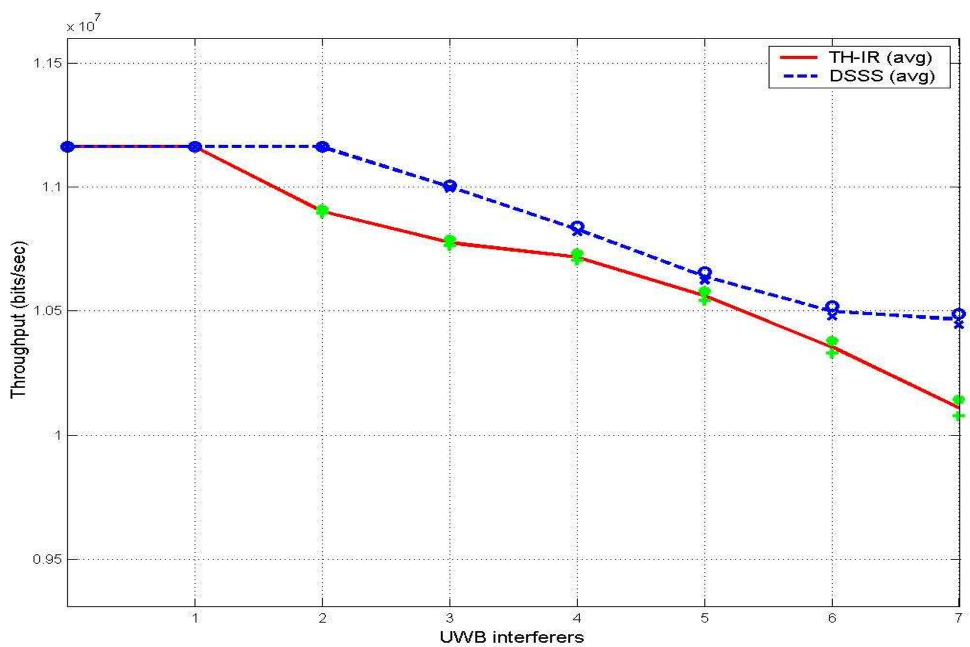

Figure 53. Throughput vs UWB Interferers (ST, STA to AP – 14 m, NM)

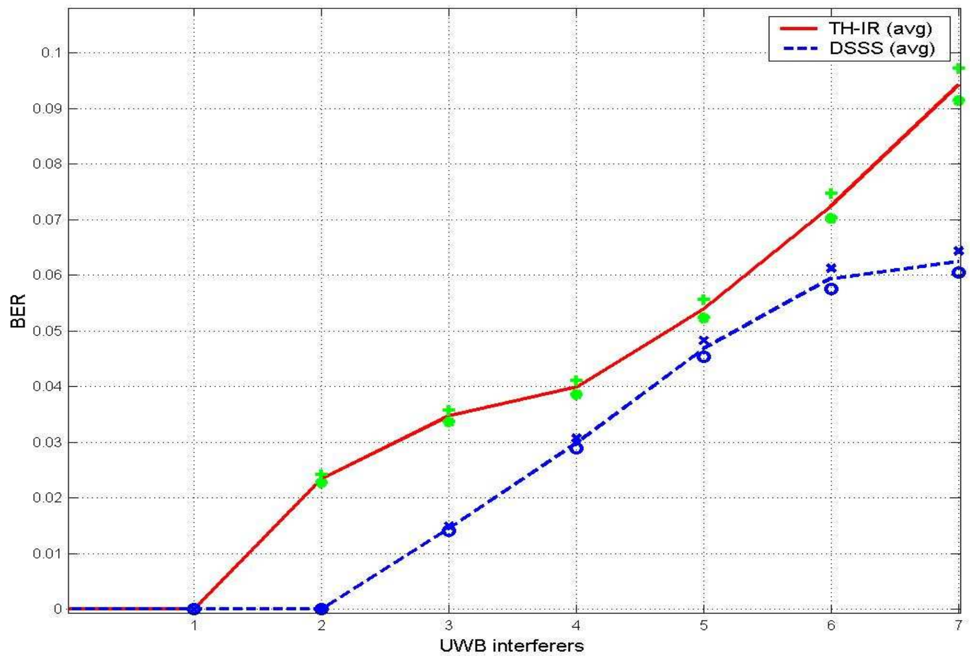

Figure 54. BER vs UWB Interferers (ST, STA to AP – 14 m, NM)

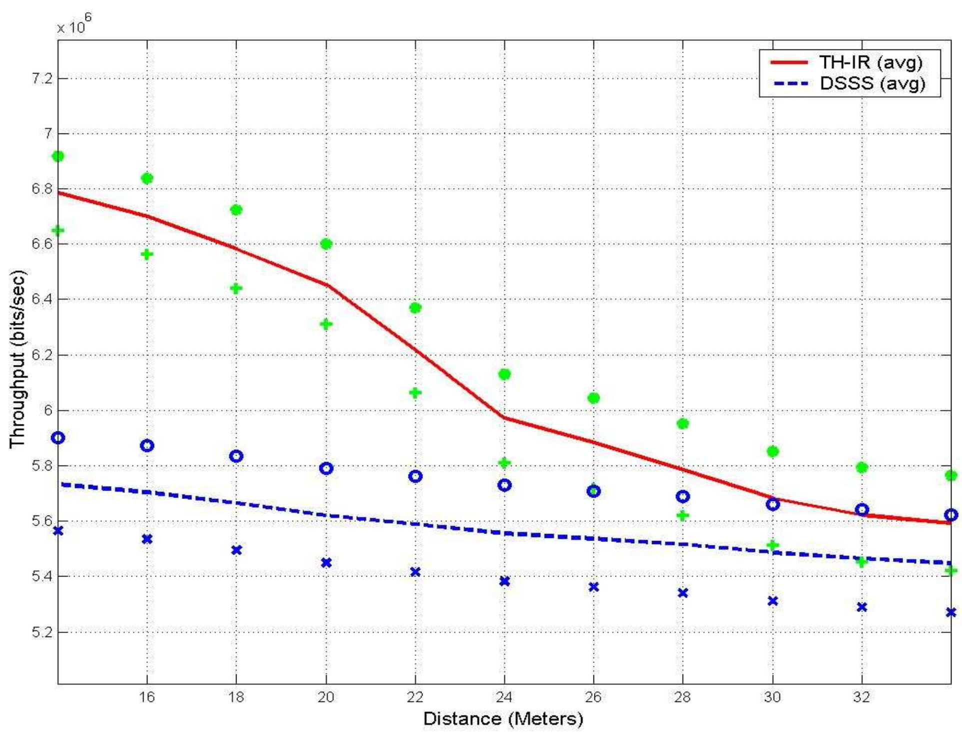

Figure 55. Throughput vs Distance (ST, 7 UWB Interferers, 30 Taps)

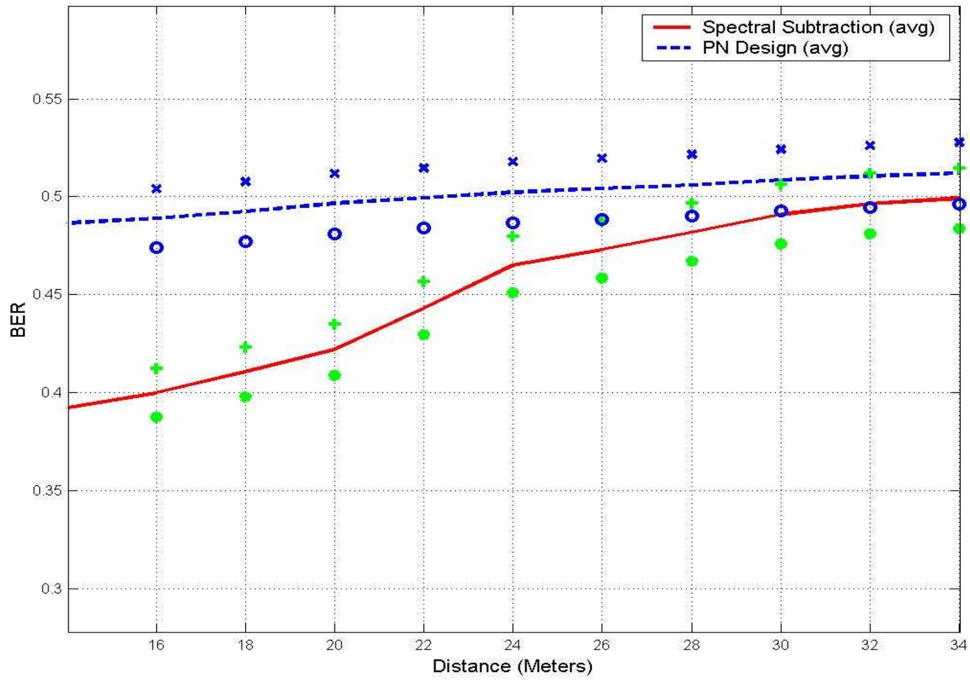

Figure 56. BER vs Distance (ST, 7 UWB Interferers, 30 Taps)

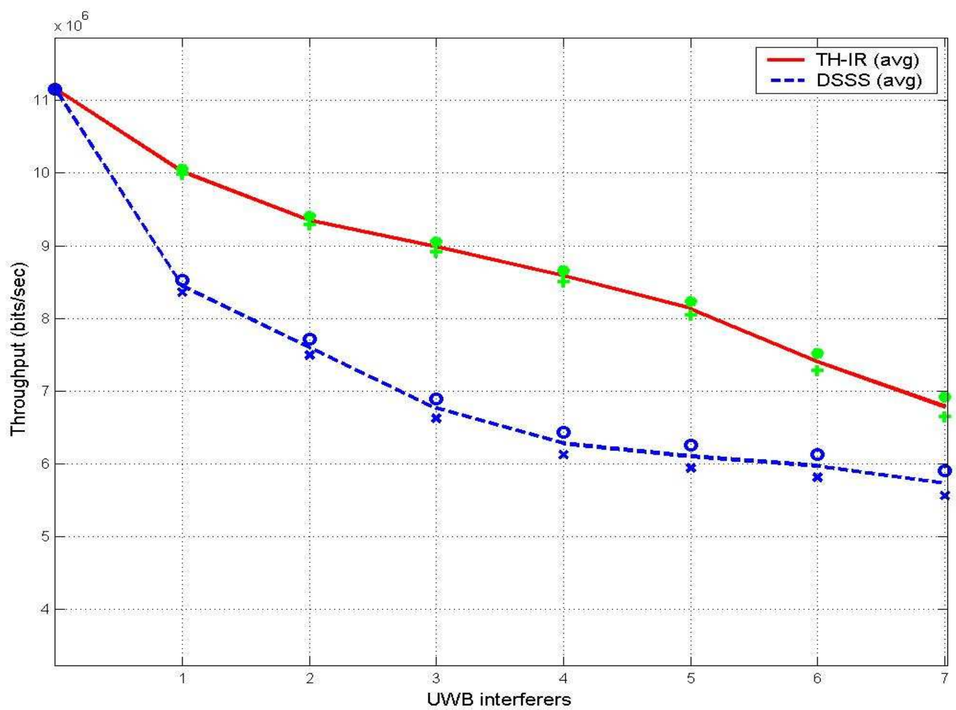

Figure 57. Throughput vs UWB Interferers (ST, STA to AP – 14 m,30 Taps)

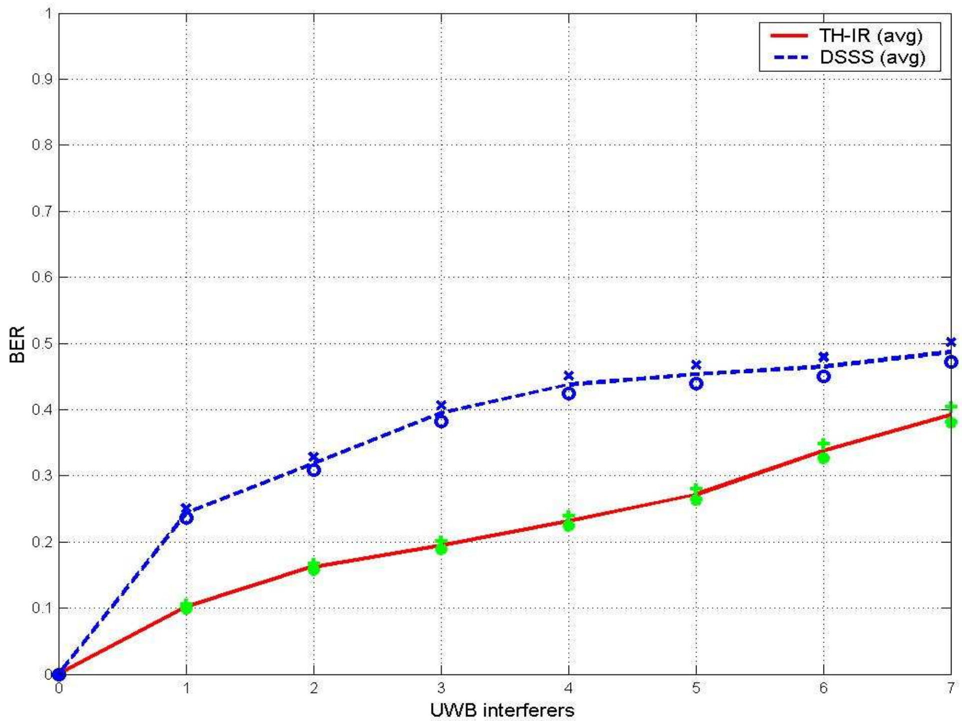

Figure 58. BER vs UWB Interferers (ST, STA to AP – 14 m, 30 Taps)

5.3.5 Comparison of Modulation Techniques

The results in Figure 59, Figure 60, Figure 61, and Figure 62 indicate that OOK performs better than BPM and PPM in the absence of multipath, i.e., the throughput and BER performances of an IEEE 802.11a WLAN system with interference from 7 simultaneous UWB systems using OOK (in absence of multipath) are better when compared to that of an 802.11a WLAN system with interference from 7 simultaneous UWB systems using BPM or PPM. However in the presence of a 30 tap channel the interference caused by OOK to the WLAN system is more than BPM and only slightly less than PPM. The results shown in Figure 63, Figure 64, Figure 65, and Figure 66 indicate that the throughput and BER performances of an IEEE 802.11a OFDM WLAN system with interference from 7 simultaneous UWB systems using OOK (in the presence of multipath) are worse when compared to that of an IEEE 802.11a OFDM WLAN system with interference from 7 simultaneous UWB systems using BPM but very slightly better than PPM. This is because multipath cancels some of the the positive and negative component of the pulses in BPM whereas in OOK and PPM multipath only increases the positive and negative component. So the increase in PSD levels is less in BPM signals than OOK or PPM signals. It has been found that in PPM the multipath appears as data modulation at the receiver [37] and so the BER of the UWB system using BPM is lower than that of PPM system. So we can see that BPM offers advantage not only in interference reduction but also in improving the performance of the UWB system itself.

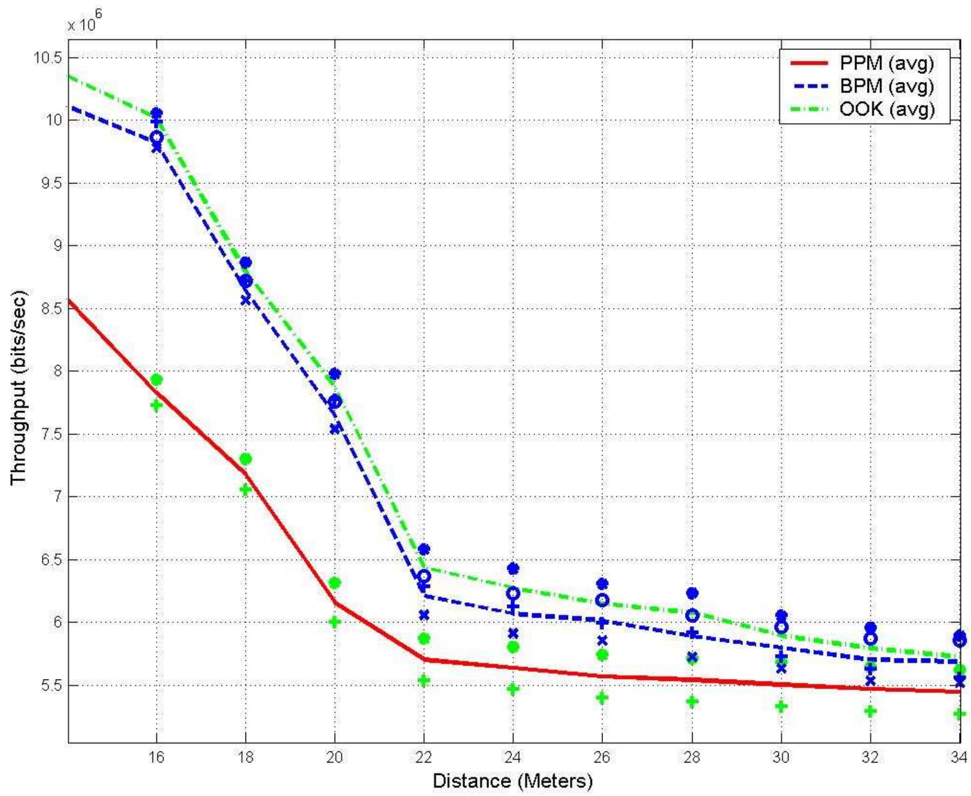

Figure 59. Throughput vs Distance (Modulation (MD), 7 UWB Interferers, NM)

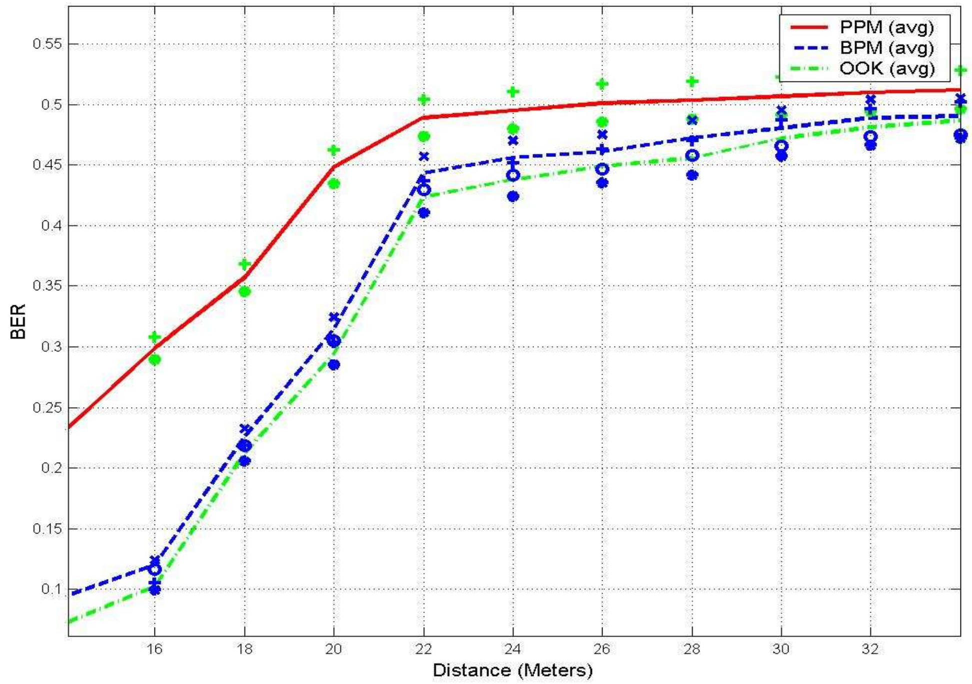

Figure 60. BER vs Distance (MD, 7 UWB Interferers, NM)

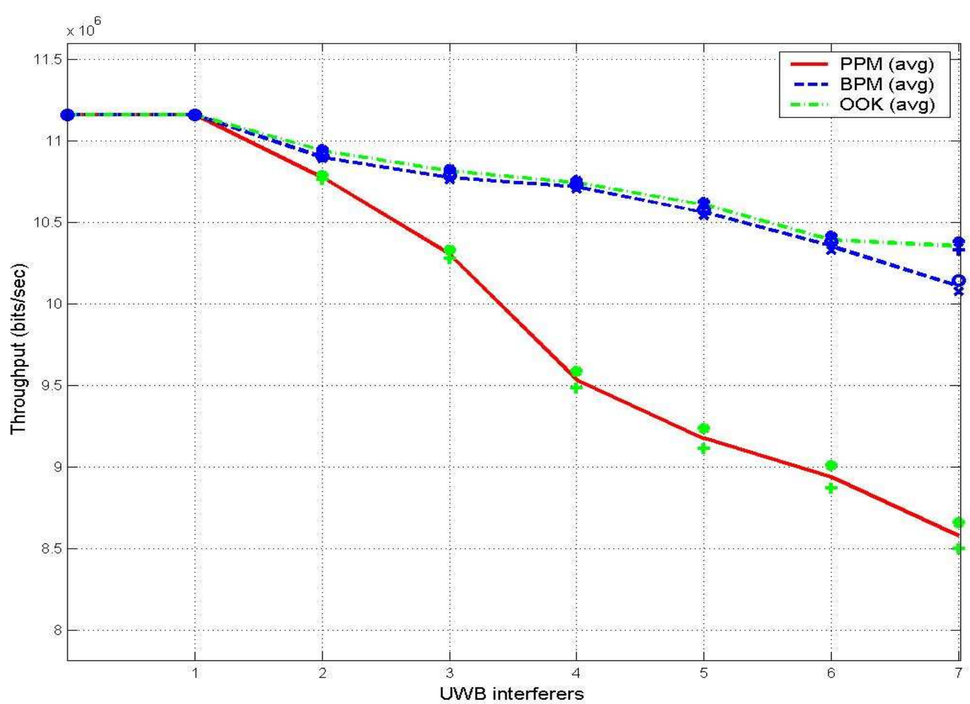

Figure 61. Throughput vs UWB Interferers (MD, STA to AP – 14 m, NM)

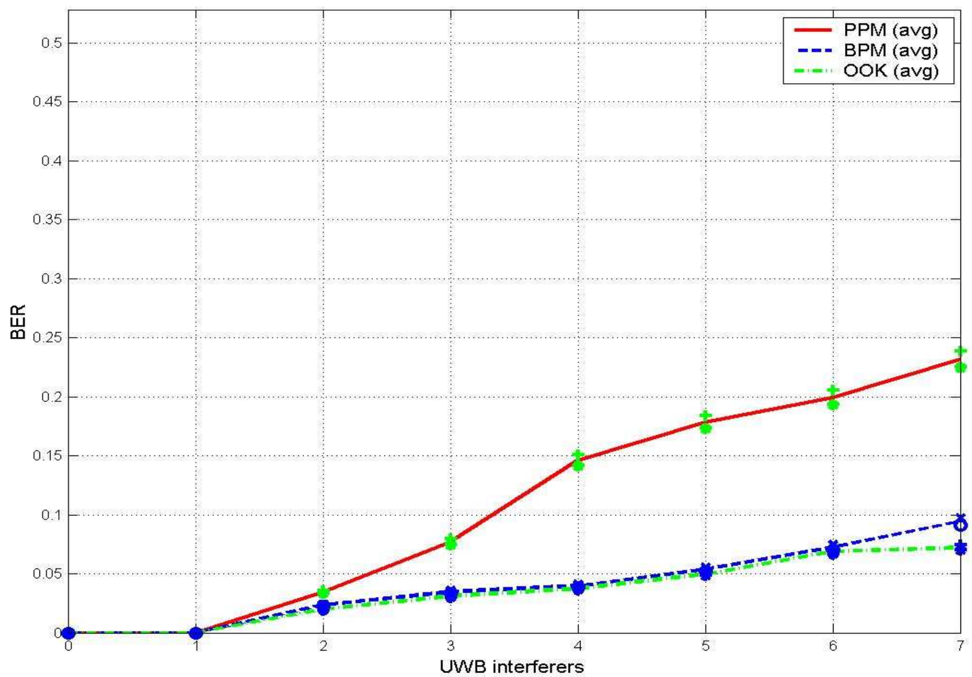

Figure 62. BER vs UWB Interferers (MD, STA to AP – 14 m, NM)

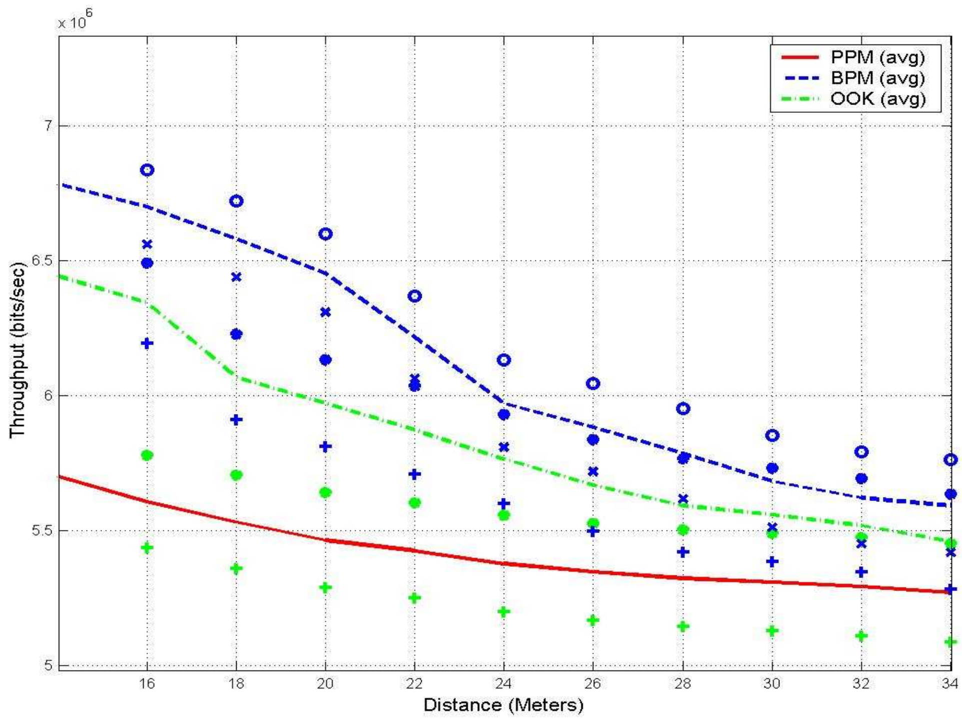

Figure 63. Throughput vs Distance (MD, 7 UWB Interferers, 30 Taps)

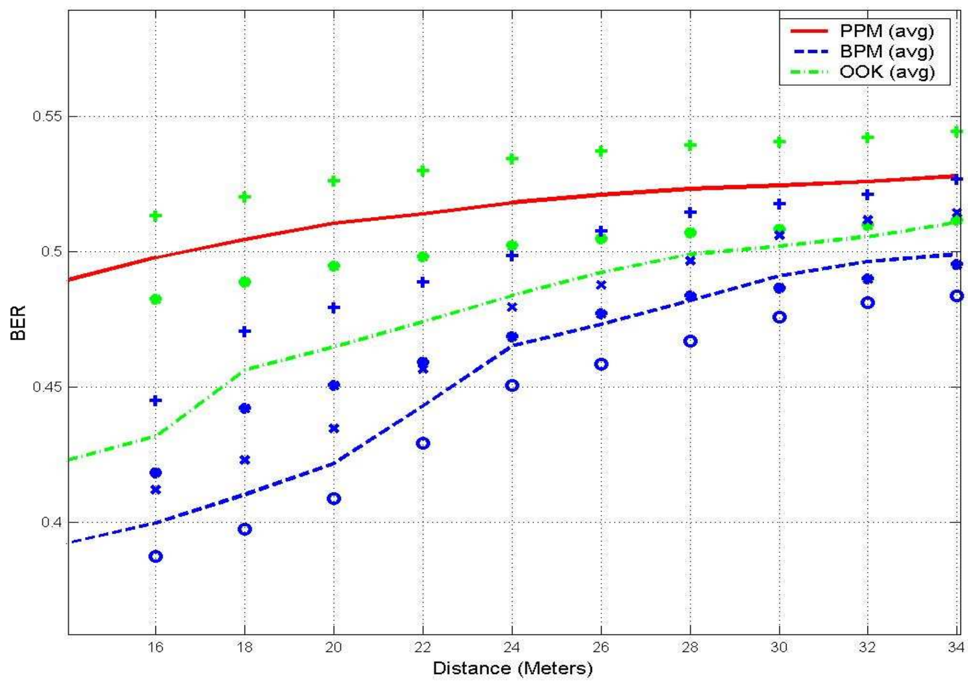

Figure 64. BER vs Distance (MD, 7 UWB Interferers, 30 Taps)

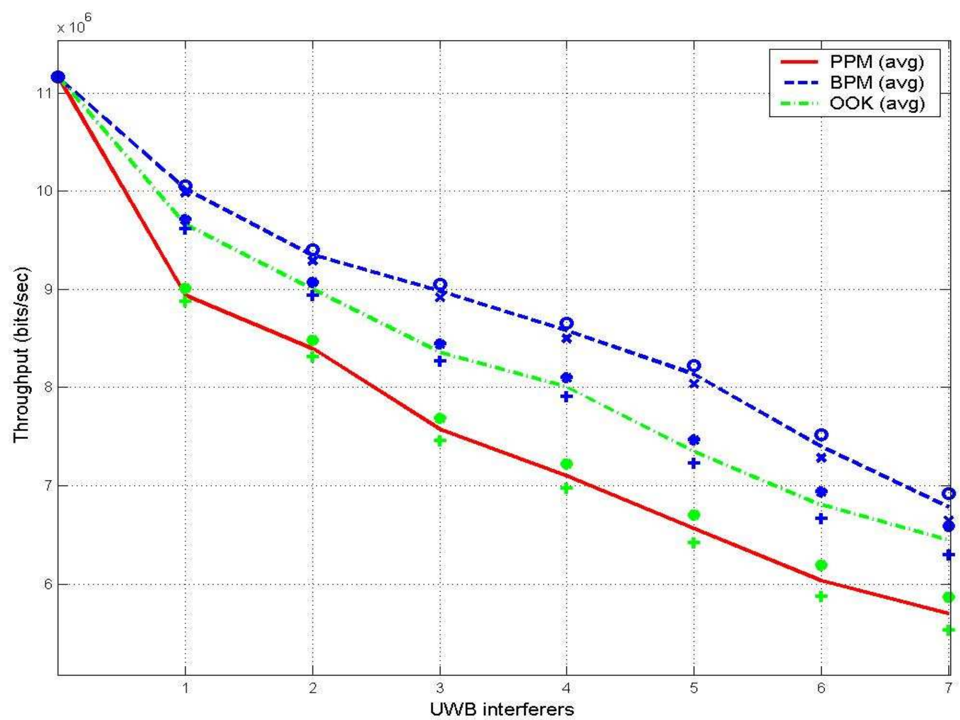

Figure 65. Throughput vs UWB Interferers (MD, STA to AP – 14 m, 30 Taps)

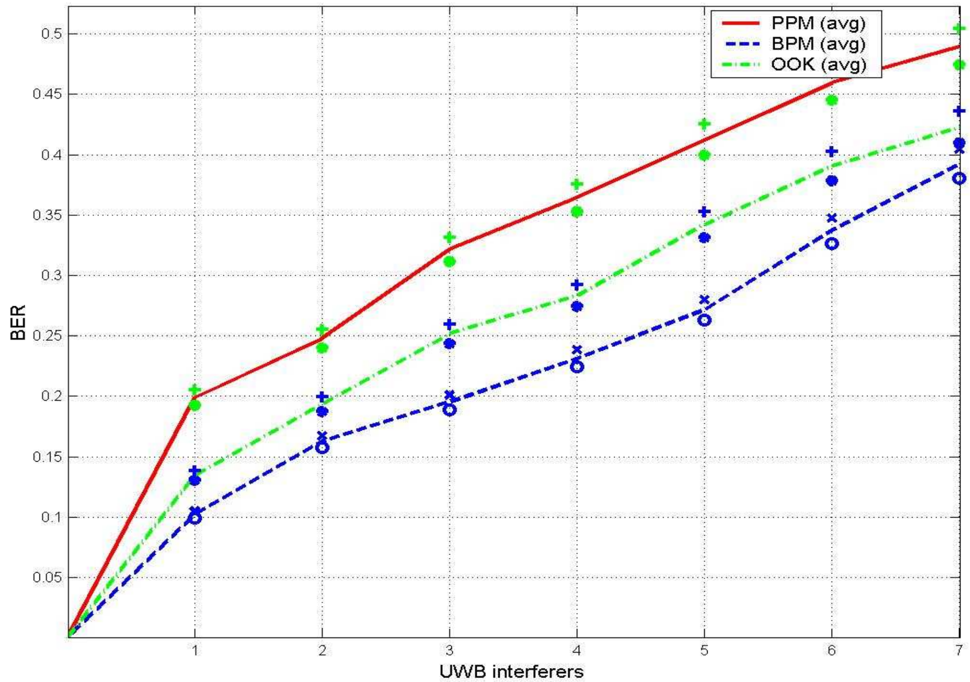

Figure 66. BER vs UWB Interferers (MD, STA to AP – 14 m, 30 Taps)

5.4 Mitigation Techniques

The following section gives the results for the comparison of two mitigation techniques (MT) that can be applied to UWB system to reduce the interference caused to the IEEE 802.11a system.

5.4.1 Comparison of Spectral Subtraction and PN Design

In Figure 67,Figure 68, Figure 69, and Figure 70, we have shown the comparison for the PN code design method for UWB spectral shaping proposed in [24] and the filtering/spectral subtraction method in the absence of multipath. The results indicate that the performance of the PN code proposed in [24] is more or less similar to the spectral subtraction technique in absence of multipath. This is because both the techniques effectively produce a notch at the affected narrowband frequency band. However, in the presence of multipath as shown in Figure 71, Figure 72, Figure 73, and Figure 74 the spectral subtraction methods performs a little better than the PN design method. This is because due to multipath the pulse positions change and the spectral properties introduced by the PN code design do not remain the same. It remains to be seen that which technique produces a better performance at the UWB receiver side. Also, which technique has lower implementation cost is a matter for further investigation. Since the spectral subtraction technique requires sending the spectrum modifying signal with every symbol it may add additional overhead at the receiver and reduce the performance of the UWB receiver. The PN design technique may add additional overhead at the transmitter for designing the code for each symbol. Also the codes for different users have to be completely orthogonal and that may add to the complexity.

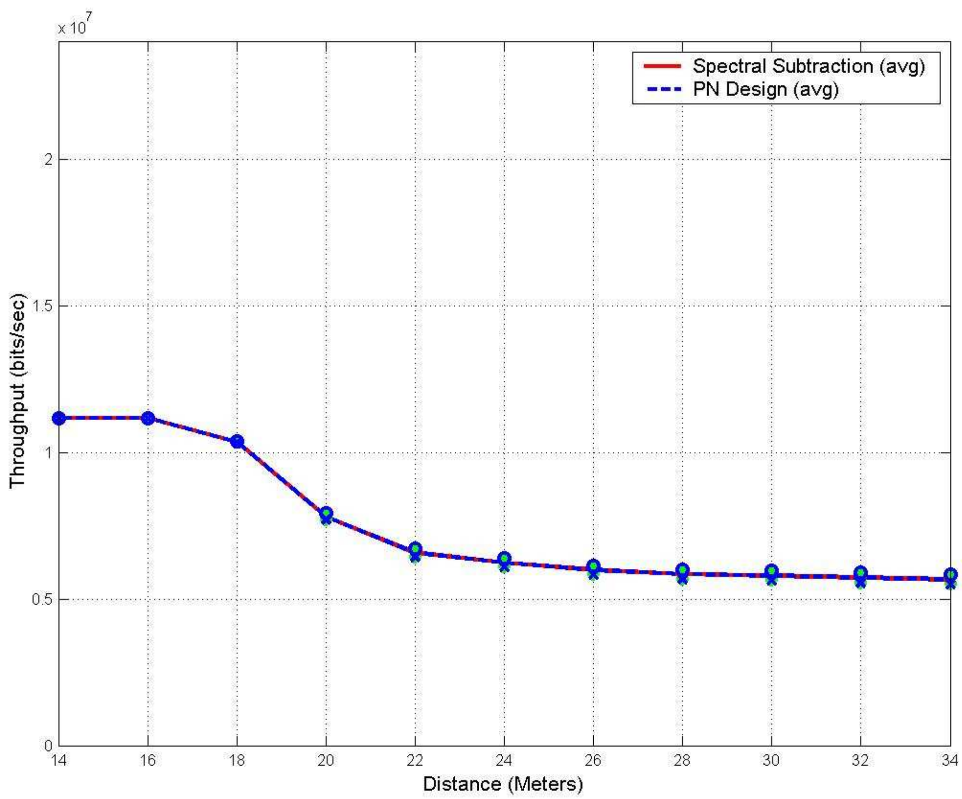

Figure 67. Throughput vs Distance (MT, 7 UWB Interferers, NM)

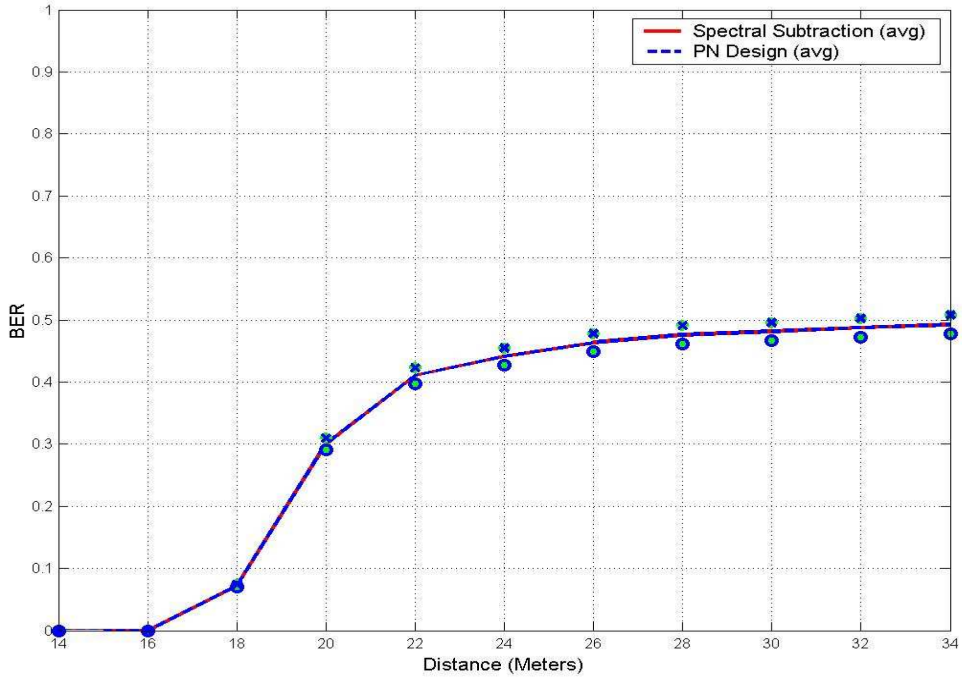

Figure 68. BER vs Distance (MT, 7 UWB Interferers, NM)

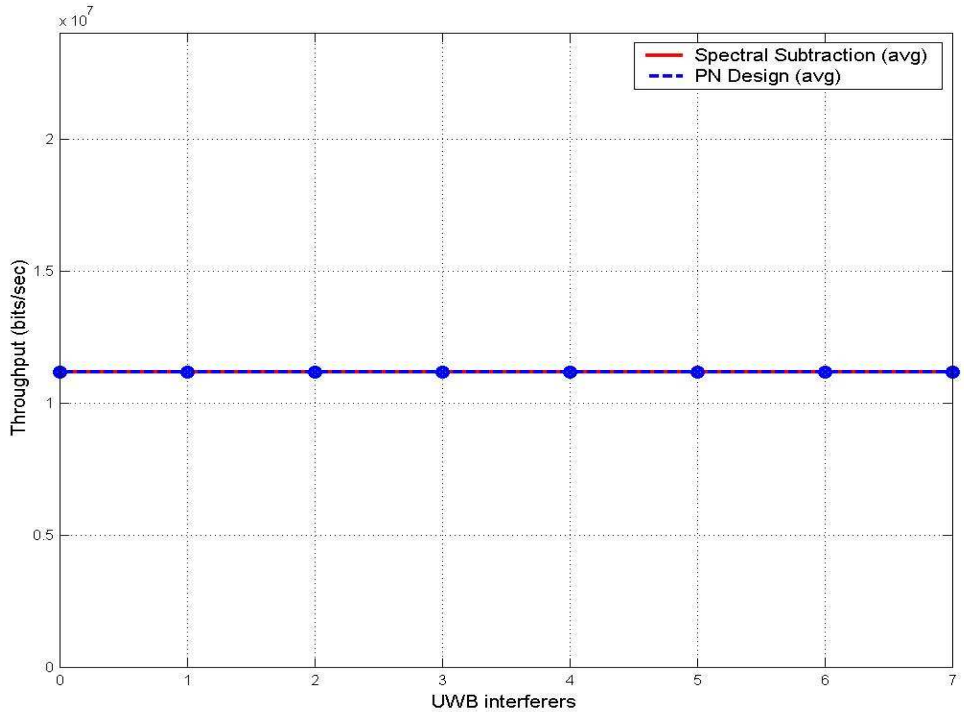

Figure 69. Throughput vs UWB Interferers (MT, STA to AP – 14 m, NM)

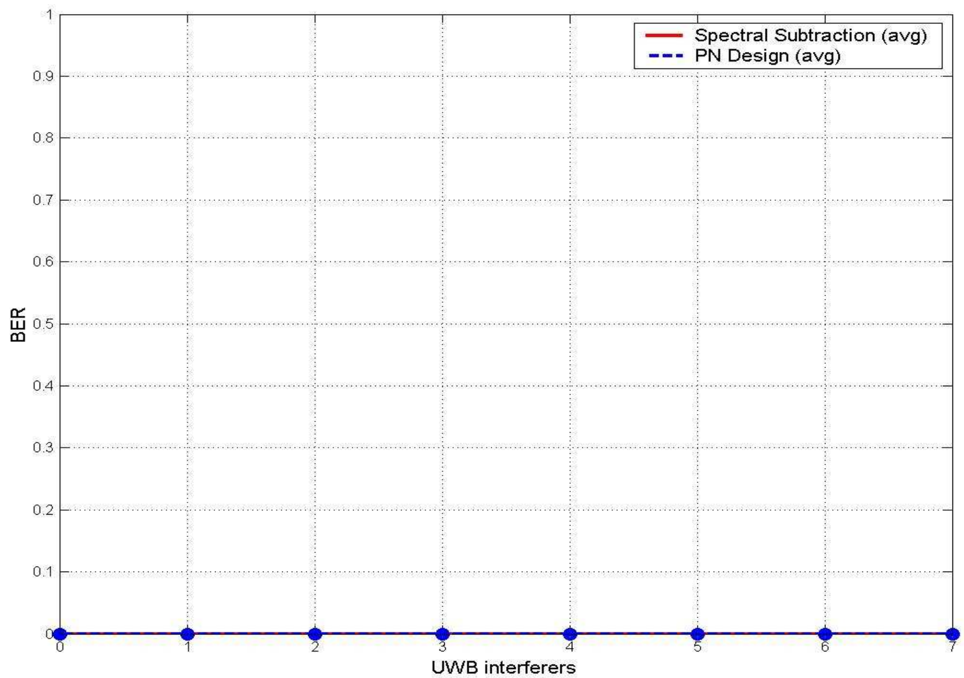

Figure 70. BER vs UWB Interferers (MT, STA to AP – 14 m, NM)

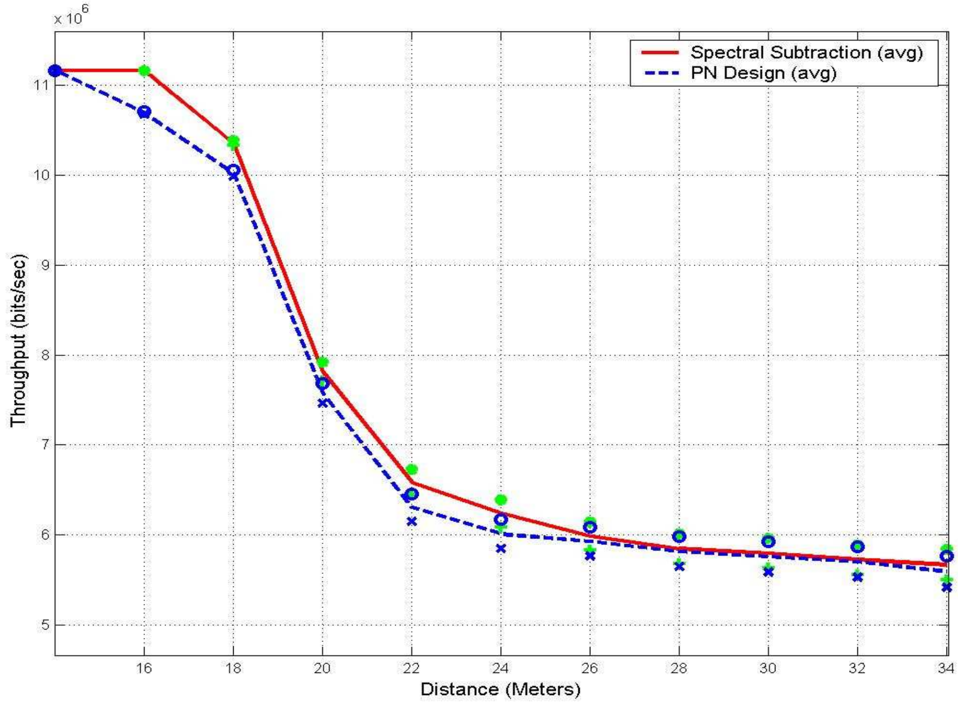

Figure 71. Throughput vs Distance (MT, 7 UWB Interferers, 30 Taps)

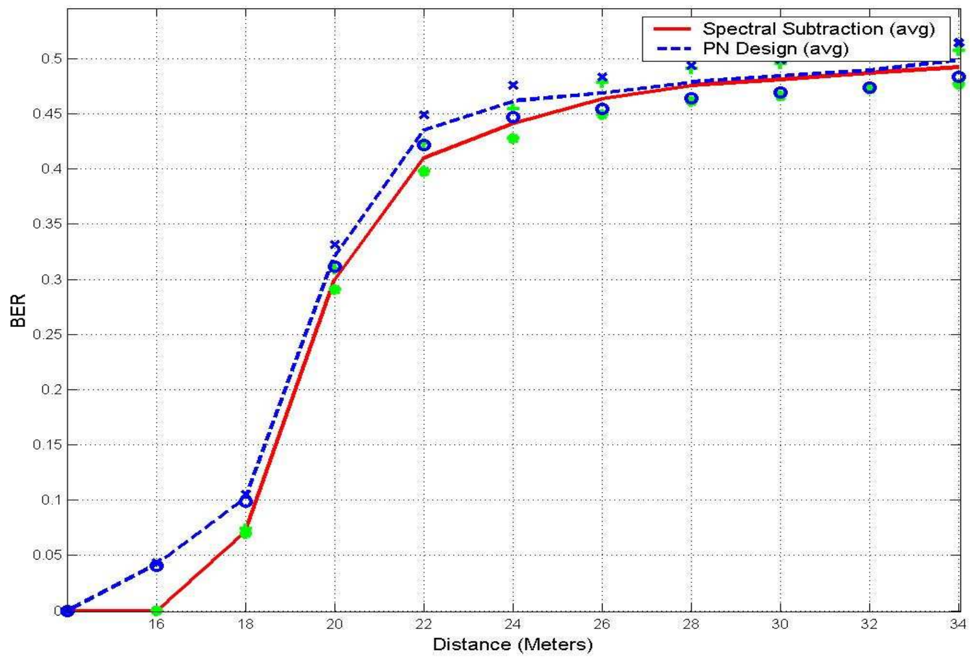

Figure 72. BER vs Distance (MT, 7 UWB Interferers, 30 Taps)

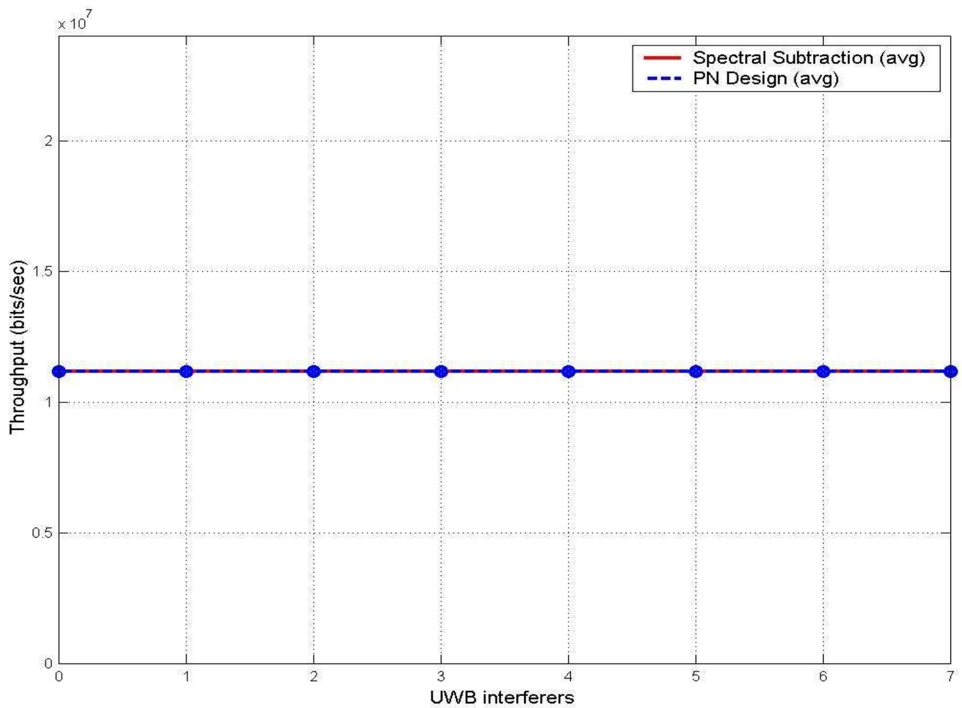

Figure 73. Throughput vs UWB Interferers (MT, STA to AP – 14 m, 30 Taps)

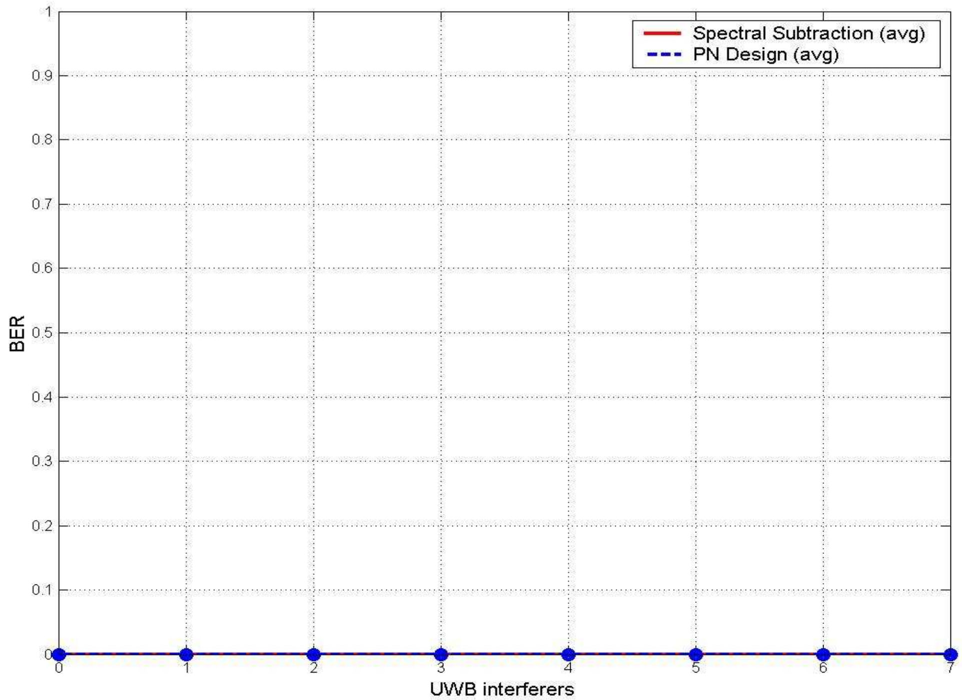

Figure 74. BER vs UWB Interferers (MT, STA to AP – 14 m, 30 Taps)

CHAPTER 6

CONCLUSION AND FUTURE WORK

In this research the effect of various parameters affecting the PSD of the UWB signal on the performance of an IEEE 802.11a OFDM WLAN has been studied for specific simulation scenarios. The parameters have also been compared both in the presence and absence of multipath for further analysis. A PN code design method proposed in [24] has been studied, implemented and its performance has been compared to spectral subtraction method. The performance of these two mitigation techniques has been tested in the presence of dense multipath.

It was found that in dense multipath a number of UWB parameters lose the advantage that they offer in a single tap channel. The higher derivative of Gaussian pulse causes less interference to WLAN systems in the absence of multipath but in the presence of dense multipath its advantage is very marginal. The narrow pulse width causes less interference than the wider pulse width in the absence of multipath but in a dense multipath environment this advantage is marginal. According to research in [14], the PRF > NBRF causes less interference than PRF < NBRF. Our research indicates that this advantage is very marginal in the absence of multipath, whereas in the presence of multipath the PRF < NBRF performs slightly better than PRF > NBRF. It was confirmed that the DSSS-UWB system causes less interference to the WLAN systems in the absence of multipath. However, our results indicate that in the presence of dense multipath the interference caused by DSSS-UWB is more than that of TH-UWB. We have confirmed that OOK UWB systems cause less interference than BPM UWB systems in absence of multipath. Both these systems cause less interference than PPM UWB. However in the presence of dense multipath the OOK UWB causes more interference than BPM UWB but marginally less than PPM UWB.

The comparison of mitigation techniques has shown that spectral subtraction and PN design both mitigate the UWB interference completely in absence of multipath. However, in the presence of dense multipath the performance of the spectral subtraction method is slightly better than that of the PN code design method.

Future work involves making a thorough investigation in the performance of the UWB receiver due to the various parameters (in the presence and absence of dense multipath) and also determining the design and implementation complexity for the UWB system with these changed parameters. The PN code design method needs to be tested with different pulse widths and different PN lengths. The best technique for interference mitigation based on the performance of IEEE 802.11a, the performance of the UWB receiver and the implementation cost involved needs to be investigated. It also involves arriving at a mathematical model for the interference caused by UWB on the IEEE 802.11a WLAN systems and looking at the interdependency of the UWB parameters.

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