UWB Co-Existence with IEEE802.11a and UMTS in Modified Saleh-Valenzuela Channel

Matti Hämäläinen, Raffaello Tesi, Jari Iinatti
Centre for Wireless Communications
P.O.Box 4500, FIN-90014 University of Oulu, FINLAND
{matti.hamalainen, raffaello.tesi, jari.iinatti}@ee.oulu.fi

Abstract —
In this paper, ultra wideband (UWB) system performance is studied in the presence of multiband interference. The interference sources considered are IEEE802.11a and UMTS which are operating simultaneously with their maximum system bandwidths. The channel model used in the study is modified Saleh-Valenzuela model which is adopted to be used as a reference UWB channel by IEEE802.15.3a study group. All the interference signals are equally powered at the UWB receiver input. The system under interest is single band and single user UWB link operating at data rate of 100 Mbps without error correction coding. UWB pulse waveforms are the 5th and the 6th derivatives of Gaussian pulse to meet the FCC regulations. In the study, both coherent and non-coherent UWB receiver algorithms are used. The former one will give a best performance due to the capability to utilize the maximum available energy at the detection process when maximum ratio combining is utilized. The results show that UWB system is sensitive to RF interference coming from the same frequency band.

1 Introduction

Co-existence issues need to be carefully taken into account to guarantee the specified quality of service for all the existing radio services sharing the same spectrum. This comes into question especially when ultra wideband system is considered. When dealing with UWB technology, the spectral overlapping issues cannot be excluded due to its extremely wide spectral usage. By the USA radio regulation authority Federal Communications Commission (FCC), the UWB signal has bandwidth greater than 500 MHz which means that the overlapping with the other RF systems is evident [1].

Recently, co-existence issues have been studied and also reports can be found from public sources. The results are utilized in the UWB standardization work, and in the major IEEE conferences UWB co-existence issues have also been covered. The published results are based on analysis and simulations, e.g. [2-3], as well as experimental tests, e.g. [4].

In this paper, we are studying UWB system performance in the presence of multiband interference. The main focus of co-existence is on the interference that is overlapping the frequency band allocated to license-free UWB systems. UWB physical layer structures exploiting both time hopping (TH-UWB) and direct sequence (DS-UWB) techniques are considered. The interfering systems are IEEE802.11a and UMTS systems which both are overlapping the FCC UWB spectrum. Typically, the published papers are covering interference that is based on only one system at time. This paper extends the approach to multiband and dual system interference.

2 System Model

UWB system under the investigation is utilizing either TH or DS UWB concept. In the former case, a pseudo random code is defining the actual pulse transmission instants within a certain frame structure, and the transmission is discontinuous which introduces silent periods to the radiated pulse train. One data bit is sent through multiple consecutive pulses to increase energy of the data bit at the receiver. The latter case is more like a conventional direct sequence spread spectrum (SS) transmission where the pseudo random code is used to spread a bit energy into multiple pulses, and change the polarity of the consecutive pulses forming one data bit. The spectrum spreading is, however, done by the narrow pulse waveform rather than having a high chip rate of the spreading code like is typically done in SS systems. In both cases, due to the pulse repetition processing gain (PG) is available at the receiver against the low received energy and interference. The system concepts are introduced in [5] in more details.

2.1 Ultra Wideband Concepts

In this paper, single band carrier-less UWB physical layer concepts are studied. The extremely narrow pulses are used to spread the signal energy over the wide bandwidth. Pulse width has been fixed to T_p = 500 ps. The 5th and 6th derivatives of the Gaussian pulse with the selected T_p are fitting the FCC mask [1] and therefore selected to the further studies. The spectra of the used pulse waveforms are presented in Figure 1 with FCC limit.

Independently on the selected physical layer (TH or DS), the transmitted data bit is spread over the multiple pulses to combat against the low signal-to-noise ratio (SNR) at the receiver. This spreading can be considered as a repetition coding, and it can be utilized to produce system processing gain. In TH-UWB, also the silent periods during the transmission can be utilized at the receiver to decrease the observed received noise energy and thus improve SNR.

The UWB receiver is utilizing both coherent and non-coherent combining algorithms with selective Rake receiver (SRake). In SRake, fixed number of multipath components out of all the possible distinguishable paths is used at the rake-receiver [6]. To capture the maximum amount of the received energy, *N* the strongest multipath components are collected for the bit decision. The other option is to use, e.g., *N* the first paths which is easier to implement due to the fixed delays in the rake fingers but is not necessary the best realization for the environments having long delay spread with strong reflectors farther from the UWB receiver.

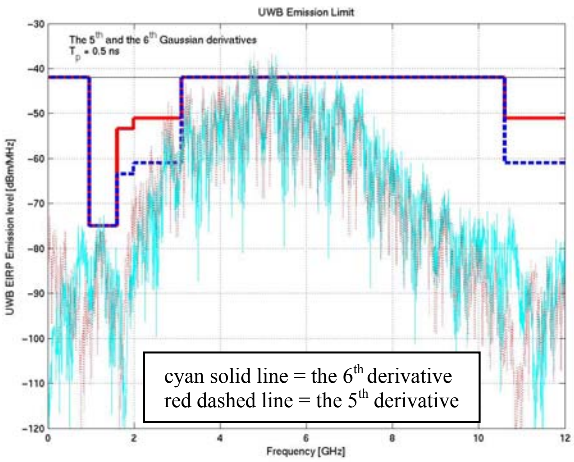

Figure 1. Spectra of the used pulse waveforms represented with the FCC indoors and outdoors radiation masks.

At the coherent receiver, the used combining algorithms are maximum ratio combining (MRC) with decision variable

$$U_i^{MRC} = \sum_{n=1}^{N} a_n^* \int_0^{T_d} r(t-\tau_n) w_i(t) dt \qquad (1)$$

and equal gain combining (EGC) with the decision variable

$$U_i^{EGC} = \sum_{n=1}^{N} e^{-j\theta_n} \int_0^{T_d} r(t-\tau_n) w_i(t) dt\,, \qquad (2)$$

where N is the number of Rake fingers used at the receiver, T_d is the data bit length, τ_n, a_n and θ_n are the delay, amplitude and phase caused by the channel, respectively. The received signal and template waveform at the correlator are defined by $r(t)$ and $w(t)$, respectively. One should notice that the template waveform presented in the equations is not the waveform of transmitted pulse but a train of pulses forming one data bit.

The non-coherent receiver calculates the decision variable using square-law combining algorithm with non-coherent power estimation (SLC+PE) that is based on the formula

$$U_i^{SLC+PE} = \sum_{n=1}^{N} \left(|a_n| \left| \int_0^{T_d} r(t-\tau_n) w_i(t) dt \right|^2 \right) \qquad (3)$$

with the same variables defined above. The used combining algorithms are described in [7] in more details. The absolute combining (AC) method has also been studied in [7] but it is excluded from this study because of the fact that SLC+PE gives the best performance from the studied non-coherent algorithms. Reference [7] gives also the optimum numbers for the Rake fingers for the different physical layer options and detection algorithms. If not otherwise stated, the receiver used in this study utilizes ten rake branches based on the results from [7]. The results presented in the paper are for raw BER, any error correction codes are not used.

In all the cases, the output of the correlator is sampled at chip rate, equaling one sample per received chip. Data rate for UWB transmission is fixed to 100 Mbps which can be reached by $PG = 13$ dB. Higher PGs lead to smaller achievable data rate, and vice versa. In direct sequence based UWB system, all this PG is produced by the pulse repetition, while in time hopping system, 10 dB is coming from pulse repetition and 3 dB from the low duty cycle (equaling duty cycle of 50%).

2.2 Interference Models

The signals used in this study to represent interfering systems are based on colored Gaussian noise (CGN) models. The center frequencies and bandwidths of the CGN are set to correspond to the spectral properties of the interfering system. Due to the large difference between the bandwidths of the UWB and interfering signal, CGN models have sufficient accuracy. Throughout the simulations, the multiband interference scenarios are obeyed. All the individual interfering channels have the same equal power at the UWB receiver, and are represented also with the results.

2.2.1 IEEE 802.11a Wireless Local Area Network

One of the wireless local area networks (WLAN) overlapping the spectra of the UWB system operating under the FCC radiation mask is IEEE802.11a. This study covers the IEEE802.11a operating at the U-NII lower and middle bands at 5.15–5.25 GHz and 5.25–5.35 GHz, respectively. The WLAN system has 8 individual 16.6 MHz channels within those two U-NII bands [8]. The centre frequencies for IEEE802.11a are presented in Table 1. Also, at the U-NII upper band 5.725–5.825 GHz, there is allocated frequency slot for IEEE802.11a but it is excluded from this study. For the simplicity, the orthogonal frequency division multiplexing (OFDM) properties of the 802.11a system are not modeled but the CGN is used. The co-existence between UWB and ODFM is studied from the OFDM point-of-view also in [9]. There the UWB effect was seen insignificant to the IEEE802.11a.

Table 1. IEEE802.11a center frequencies. Bandwidth of the individual WLAN channel is 16.6 MHz.

Band [GHz]	Center frequency [GHz]
U-NII lower (5.12-5.25)	5.18
	5.20
	5.22
	5.24
U-NII middle (5.25-5.35)	5.26
	5.28
	5.30
	5.32

2.2.2 UMTS Cellular System

The other simultaneously interfering “narrowband” system is UMTS whose uplink (UL) and downlink (DL) bands in frequency division duplex (FDD) mode are modeled as fully loaded using also CGN. UMTS FDD-UL and DL bands are between 1.92–1.98 GHz and 2.11–2.17 GHz, respectively. There will also be two TDD (time division duplex) bands between 1.9–1.92 GHz and 2.01–2.025 GHz. Because in the first phase of UMTS only FDD modes are used TDD bands are excluded from the study. The UMTS physical channel bandwidth is B = 3.84 MHz [10]. Due to the assumption of fully loaded UMTS system the bandwidths of the CGN are 60 MHz which are located in both UL and DL bands.

2.3 Channel model

The UWB system performances are studied using the modified Saleh-Valenzuela (SV) channel models [11-12] which are adopted by the IEEE802.15.3 as a reference model to be used in UWB system studies. SV-models are not based on the UWB channel soundings, but have been selected to be used as a first reference model. In this study, two out of four defined SV-models have been utilized. The model SV1 describes the line-of-sight (LOS) channel from 0–4 m. The other model, SV3, is derived for non-line-of-sight (NLOS) link for the distances between 4–10 m. The RMS delay spreads for SV1 and SV3 are 5.28 ns and 14.28 ns, respectively. SV2 and SV4 models that are now excluded are also representing NLOS links for the distance range 4-10 m.

3 Results

This chapter shows the simulation results for the different UWB physical layer structures introduced in the preceding chapters. All the receivers are ten fingers selective Rake receivers if not otherwise stated. The single-user UWB system is assumed to have a perfect synchronization and error correction coding was not used. The signal-to-interference ratio (SIR) in the results can be calculated from the information presented in the legends of the figures. In the case of P_I = 10 as marked in the legend, SIR is -10 dB for one interferer due to the UWB signal power of 0 dBm used at the simulations for the one data bit, and +10 dBm interference power used by the interferer. If there are ten interference sources the cumulative interference power at the input of UWB receiver is ten times more as the one mentioned in the legend.

In Figure 2, the bit-error-rate curves are presented for the UWB system utilizing binary pulse amplitude modulation (BPAM). Due to the bipolar modulation technique, only the coherent receiver algorithms could be used. The results for both EGC and MRC are represented for the Gaussian 5th pulse. The interference is based only on eight WLAN channels.

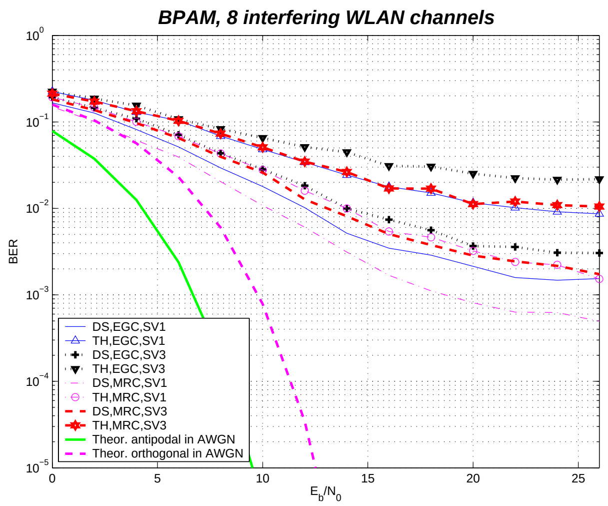

Figure 2. Simulated UWB-BER’s at Saleh-Valenzuela channel with MRC and EGC for BPAM. Power levels of the 8 WLAN channels are 10 dBm each.

MRC outperforms EGC in all the cases as was expected. However, if one compares the rank order, e.g., to the results for AWGN channel presented in [5] where either the UMTS uplink or downlink signal is interfering UWB system, the order between DS or TH performances has been changed. In the realistic channel, DS system seems to outperform the corresponding TH one. E.g., the difference between DS-MRC and DS-EGC in SV1 channel is 4.9 dB in the BER-level of 0.002. At the same level, the difference between DS- and TH-MRC is 9.1 dB. In AWGN channel the difference was about 1 dB in advance of TH [5]. In TH-UWB, the inter-pulse interference (IPI) is smaller than in the corresponding DS-UWB. However, due to the fine delay resolution of the UWB system the consecutive paths can be distinguished.

Figure 3 gives the results for PSM. The Gaussian 5th and 6th derivatives were used to transmit data bit “0” and

"1", respectively. The detection is based on non-coherent SLC+PE approach (Eq. 3). The interference is coming from both WLAN and UMTS, and the individual channel gives 5 dBm interference powers to the UWB receiver. The results showed that DS-UWB outperforms the corresponding TH-UWB system also in non-coherent case. The DS performance in SV3 channel gives approximately the same result than the TH in SV1 channel, in which the total energy is spread in fewer paths and shorter time.

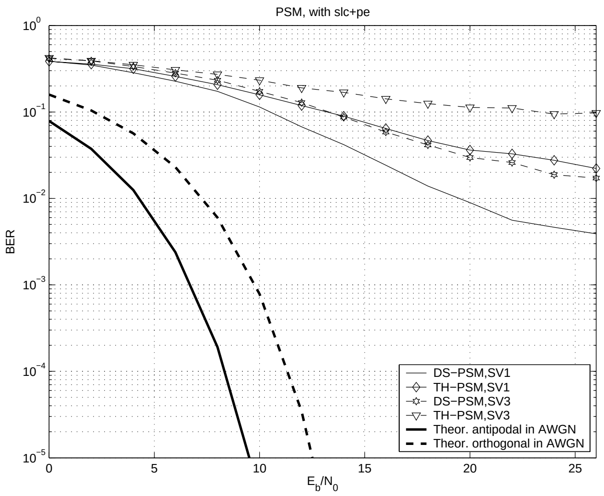

Figure 3. Simulated UWB-BER's at Saleh-Valenzuela channel with non-coherent combining utilizing PSM with 10 interference sources each having power of 5 dBm.

In Figure 4 the used modulation scheme is still PSM. The curve crowds represent the performances of coherent detection using different numbers of Rake branches, and non-coherent detection with different interference power levels but fixed number of rake fingers. When comparing the results of MRC and SLC+PE from Figure 4, one can notice that the former one stands for the severe interference. In non-coherent case, the interference is based only on WLAN signals, but in MRC case, also UMTS interference is present. The difference is still more than 5 dB for MRC.

Table 2 summaries the required SNR values for binary pulse amplitude modulation when the interference is coming only from IEEE802.11a. Due to the bipolar modulation scheme only the coherent receiver algorithms are covered. In Table 2, the results are based on the situation where the interferences are coming from both WLAN (8 channels) and UMTS (2 channels).

For pulse shape modulation the required SNR values for bit-error-rates 10^{-2} and 10^{-3} can be found from Table 3. The used receiver algorithms have been MRC, EGC and SLC+PE.

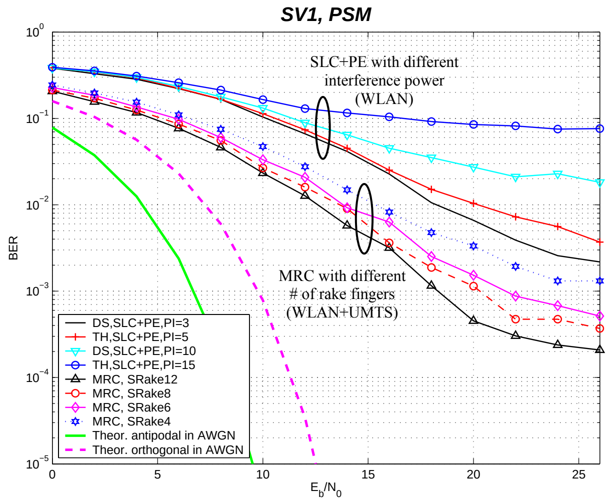

Figure 4. Simulated UWB-BER's at Saleh-Valenzuela channel with different interfering power levels and different number of Rake fingers.

Table 2. Required SNR values in dB for coherent BPAM at BER 10^{-2}. Each interference channels have power of 10 dBm.

	DS		TH	
BER 10^{-2}	SV1	SV3	SV1	SV3
MRC	10.27	13.05	13.98	26.08
EGC	12	14	22	-

Table 3. Required SNR values in dB for coherent and non-coherent BPSM to reach BER 10^{-2} and 10^{-3}. Each interference channel has power of 5 dBm.

		DS		TH	
	Srake10	SV1	SV3	SV1	SV3
MRC	BER 10^{-2}	13	15	19.8	-
	BER 10^{-3}	19	26	-	-
EGC	BER 10^{-2}	14.09	16.24	-	-
	BER 10^{-3}	22	-	-	-

The UWB system performance is saturating to the certain level when the interference is present. The saturation level depends on the available processing gain and the level of interference. If lower BER is required, the data rate needs to be decreased to get higher processing gain, or the pulse energy needs to be increased. Based on the results from [7], increasing the Rake fingers improves only the performance of MRC and the other receiving algorithms tends to get poorer performance, also with increasing E_b/N_0.

4 Conclusion

In this paper we have studied the performance of the different single band UWB systems through bit-error-rate simulations in the modified Saleh-Valenzuela model in the presence of interference coming from the multiple IEEE802.11a channels and UMTS up- and downlinks simultaneously. The UWB receiver is utilizing maximum ratio, equal gain and square law combining with power estimation detection technologies. The studied UWB physical layer concepts were time-hopping and direct sequence based systems with binary pulse amplitude and pulse shape modulations. The selected interfering systems and the studied UWB system are utilizing the same frequency band which means inevitable cross-talk between the devices.

Based on the simulation results, the coherent receiving algorithms are preferable to non-coherent one as expected. MRC outperforms the EGC and SLC+PE with 6.6 dB and 5 dB in SV1 channel at BER-level 10^{-2}, respectively with DS-PSM. In SV3 channel the difference between MRC and EGC is approximately 1 dB, and the non-coherent detector saturates before the studied BER-level. The difference between DS and TH is at least 6 dB for orthogonal and 3.5 dB in antipodal cases in SV1. If the better BER performance is needed the data rate of the UWB system needs to be decreased, pulse energy increased or error control coding is need to be implemented.

5 Acknowledgment

This study has been financed by the National Technology Agency of Finland (Tekes), Elektrobit and the Finnish Defence Forces, and also by European Commission through Ultrawaves-project (EU IST-2001-35189). Hämäläinen is also funded by Nokia Foundation grant. The authors would like to thank all the sponsors for their support.

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