Ultra Wideband System Performance Studies in AWGN Channel with Intentional Interference

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Abstract: This paper studies the performance degradation of ultra wideband (UWB) radio system in intentionally interfered AWGN channel. Simulated UWB systems utilize pulse shape (PSM), pulse position (PPM) and pulse amplitude (PAM) data modulation schemes. All the modulation schemes are binary. The pulse waveforms used in the study are based on a Gaussian pulse, being its first four derivatives. Interference model is coloured Gaussian noise, having 60 MHz bandwidth at both UMTS uplink and downlink bands. The results showed that PAM modulation outperforms the other studied modulation schemes. If PSM is used, the selection of the used pulses set also the sensitivity against interference. PPM modulated system retains its performance while the interfering power is increased. However, its overall performance is the worst among the implemented modulations.

1. Introduction

According to the regulations, radio system is classified as an ultra wideband (UWB) if its bandwidth is greater than 500 MHz, or its fractional bandwidth is greater than 20% [1]. In this study, the pulse waveforms used are satisfying these requirements.

The most common carrierless UWB data modulation schemes used in the proposed communication applications nowadays are pulse position (PPM) and pulse amplitude (PAM) modulations. Including these schemes, this paper studies also a performance of an UWB system based on pulse shape modulation (PSM) that also allows one to get an orthogonal signalling. Multilevel (M>2) modulation schemes are excluded from this study.

The system comparison has been made by bit-error-rate (BER) simulations. The goal of the study is to rank the performance of different UWB system concepts in interfered environment. Interference in our case is located both at the UMTS-FDD uplink and downlink bands at the same time. Reference results where only one of the listed bands is interfering can be found from [2].

2. UWB System Model

The studied physical layers are based on time hopping (TH) and direct sequence (DS) techniques applied to UWB context. In [2], a more detailed description of the studied system concepts can be found.

The TH-UWB model used in this study corresponds to the conventional impulse radio [3] where the discontinuous transmission instants are controlled by a pseudo random time hopping code. Because the pulse repetition interval in TH system is much longer than the pulse widths, received noise power level can be reduced by keeping the receiver off during the periods when the user of interest is in silent mode. In multi-user case, all the users have different time hopping pattern to avoid collisions.

The studied pulse waveforms are the first four derivatives of the Gaussian pulse represented in Figure 1. Based on [4] the antennas are modelled as a differentiation operation. During the simulations, all the timing and synchronization procedures are assumed to be ideal.

DS-UWB model corresponds to the conventional DS spread spectrum (SS) technique having chip waveforms from Figure 1. In DS-UWB, however, high chip rate is not used for the spectral spreading, but a DS code is used for user separation.

The following results are presented for a single user scenario. The effects of multiple access interference in the corresponding UWB systems are studied in [5]. To decrease the simulation times the average power and the total processing gain (PG) of the studied UWB link are fixed to P_{UWB} = 0 dBm and PG = 20 dB, respectively. Because the relative rank order is studied the PG limitation does not impair the generality of the results.

A. Pulse Position Modulation

In a binary PPM modulation scheme the information is conveyed with the time shifts between the nominal and actual pulse transmission instants. If the pulse is sent during the actual transmission time that is defined by the user specific pseudo random code, bit is “0”. If the transmission instant is delayed of a certain time instant that is related to the modulation index of the system δ, the transmitted bit is “1”.

In an AWGN channel the performance of PPM modulated signal is related to the used δ due to the cross-correlation properties of the pulse waveforms [6]. In this study, the optimal δ that gives a better performance than the theoretical probability of error of orthogonal signals. As a matter of fact, if δ <1, the cross-correlation of the two pulses related to bit “0” and “1” can give negative values. Optimal δ is related to the radiated pulse waveform, and it corresponds to the time shift of the pulses that gives the minimum value of correlation. Values for the used waveforms are presented in Table 1 [6]. PPM modulation is implemented only to TH-UWB concept.

Table 1. Optimal PPM modulation indexes δ for different pulse waveforms.

Waveform	Optimal δ
1st pulse	0.292683 * T_p
2nd pulse	0.243902 * T_p
3rd pulse	0.219512 * T_p
4th pulse	0.195122 * T_p

B. Pulse Shape Modulation

The radiated pulse waveform pairs used in the PSM case have been presented in Figure 1. The pulse widths associated to the both data bits are equal. In PSM, the selection of the waveform pair affects the spectral allocation of the transmitted signal, and due to that, the tolerance against the interference. PSM is not an original invention even in UWB context. Further information can be found in [7].

As one can notice from the cross-correlation results in Figure 2, some of the pulse pairs form an orthogonal set, and almost antipodal sets can be found as well. In addition to the coherent methods, an orthogonal pulse pair that has cross-correlation zero can be used also in non-coherent systems. BER curves will follow the shape of the cross-correlation function if the signal-to-noise ratio (SNR) is fixed. Using orthogonal pulses in AWGN channel, the performance of PSM modulated UWB system equals the performance of PPM. In the interference case, the performance is related to the spectral properties of the different pulses used in the UWB system.

In this paper, both TH- and DS-UWB concepts are implemented using PSM data modulation.

C. Pulse Amplitude Modulation

In a binary PAM data modulation scheme, different pulse waveforms, or their amplitude reversed versions are sent, giving an antipodal pulse set if the timing is ideal. This modulation scheme can be used in coherent UWB systems. PAM is studied both in TH- and DS-UWB concepts.

3. Interference Model

Interference in the study is modelled using coloured Gaussian noise (CGN) that is a band-limited version of the Gaussian white noise (see Figure 3). The interference is simultaneously located to the UMTS FDD bands, both in uplink (UL, f_c = 1.95 GHz) and downlink (DL, f_c = 2.14 GHz) bands at the same time. Interfering signal having 60 MHz bandwidth at both bands is representing a fully loaded UMTS system.

Unless otherwise mentioned, the total interference power in fixed to P_I = +10 dBm, that is equally distributed to the UL and DL bands, keeping the signal-to-interference ratio (SIR) in the simulation as SIR = -10 dB.

4. Simulation results

This chapter represents the simulation results based on the assumptions introduced in the previous chapter. UWB system performances (BER) are studied as a function of SNR or SIR. The processing gain of the studied UWB system is fixed to PG_{UWB} = 20 dB to fasten the simulations. Keeping T_p = 0.5 ns and PG_{tot} = 20 dB, the data rate in the studied cases is R_d = 20 Mbps. In time hopping case, the processing gain is evenly divided between the gain coming from repetition coding and the gain coming from the low duty cycle. Due to the similar simulation assumptions the presented results are comparable to each others.

The simulation results for the UWB system utilizing PSM modulation are presented in Figure 4. If one compares the BER results to the cross-correlation values from Figure 2, a straightforward connection can be seen. The pulse pairs based on the Gaussian 1st and 3rd pulses and 2nd and 4th pulses (n^{th} derivatives of the Gaussian pulse) are forming almost an antipodal pulse pair, and the corresponding performances give relatively the best results. With the used SIR assumption the theoretical curves are almost reached with those pulse pairs. If the pulses are selected otherwise, an orthogonal performance can be reached. Figure 4 shows that independently of the used pulse pairs, significant difference between TH and DS concept cannot be seen.

Figure 5 gives a summary on the performance of PAM, PPM and PSM modulated systems as a function of increasing interference power. In PPM case, the difference in the performance based on the orthogonal ($\delta = 1$) and the optimal ($\delta = \delta_{opt}$) modulation index values can be seen. In optimal case, δ_{opt} is taken from Table 1. The UWB performance starts to degrade when the UMTS interference signals are about 20 dB higher than UWB signal level. 20 dB is also the value of the processing gain.

Figure 6 represents the simulated performance curves for the pulse shape modulated (PSM) ultra wideband systems using different pulse widths. In different subfigures the pulse pairs associated to the bits "0" and bit "1" are changed. The best simulated performance can be reached when the pulse pair is based on the Gaussian 2nd and 4th pulses. The pairs using Gaussian 1st and 2nd, 1st and 4th and 3rd and 4th pulses do not differ significantly to each others. The reasons for the difference in performance are related to the spectral properties of the pulses and interference. If the interfering signals and the used UWB pulses are overlapping in the frequency domain the degradation in the system performances is highest.

Figures 7a-b present the performance of PPM and PAM modulated UWB systems in AWGN channel when the UMTS uplink and downlink bands are interfering. In PPM case, pulse widths T_p = 0.5 ns and T_p = 1.0 ns are studied. As a reference, also the results for the case when only UMTS UL band is interfering with the same total power level have been presented. It can be noticed that PPM systems using pulses related to higher orders of derivatives of the Gaussian pulse outperform the basic ones (1st, 2nd pulses). Comparing now the results between the two pulse widths, one could notice that the system performance is worse with the longer pulse. The reason is that in this case the spectrum of the desired signal moves towards the interfering band, that is, to lower frequencies. With a certain T_p the UWB spectrum will eventually overlap the spectrum of the interfering signal. Due to the spectral allocation the UWB system can tolerate even high dual band interference because the spectra are not overlapping although the UWB bandwidth is in a class of GHz.

Figure 7b represents the comparison between the pulse waveforms both in DS and TH cases for different waveforms when modulation scheme is PAM. Based on the results obeying the simulation assumptions used, the impact of the interference on UWB system is insignificant. However, also here the higher order pulses give better performance if compared to the lower order pulses.

5. Conclusion

This paper studies single user UWB system performance in AWGN channel when interference is coming from both the UMTS uplink and downlink bands. Time hopping and direct sequence based UWB systems having pulse waveforms based on first four derivatives of Gaussian pulse are used in the study. The modulation schemes implemented are pulse position, pulse amplitude and pulse shape modulations. All studied modulation schemes are binary.

The simulation results indicate that the dual band interference degrades the PSM system worst. However, if the pulse pair is based on the 2nd and 4th derivatives of the Gaussian pulse, the effect of the interference is only 1 dB in a BER level of 10^{-3} if compared to the performance in pure AWGN channel. In the case of the other pulse pairs the performance degradation is 3-5 dB. PAM outperforms the other studied modulation schemes and there cannot be seen significant difference between TH and DS concepts.

PAM outperforms also the other modulation schemes if the sensitivity against the interference power is taken into account. The performance starts to degrade after the interference is 24 dB higher than the UWB signal. The most sensitive modulation scheme is PSM. However, PPM modulation retains the same performance level while the interference increases, although its overall performance is the worst.

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7. References

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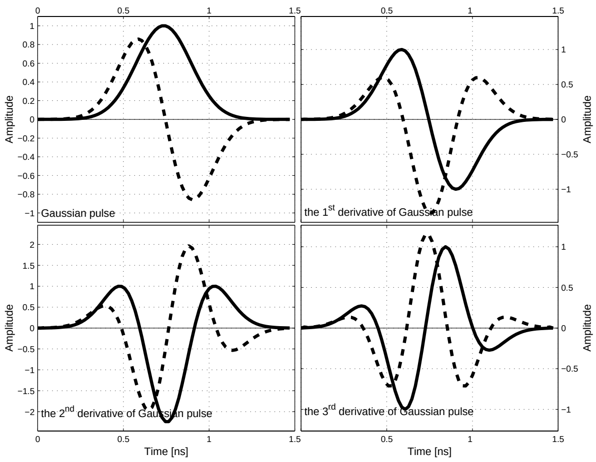


Figure 1. Pulse waveforms and waveform pairs for PSM modulation used in this study.

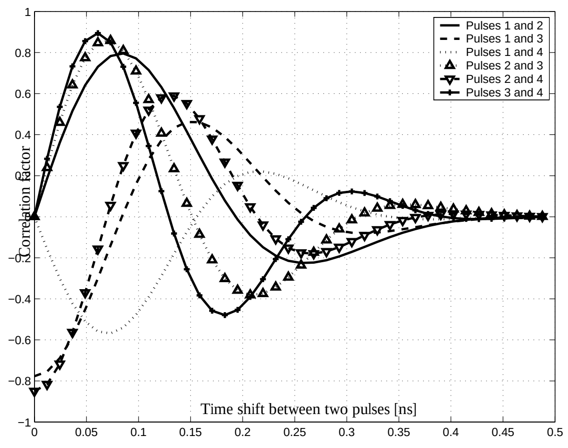


Figure 2. Cross-correlations between different pulse waveforms in PSM.

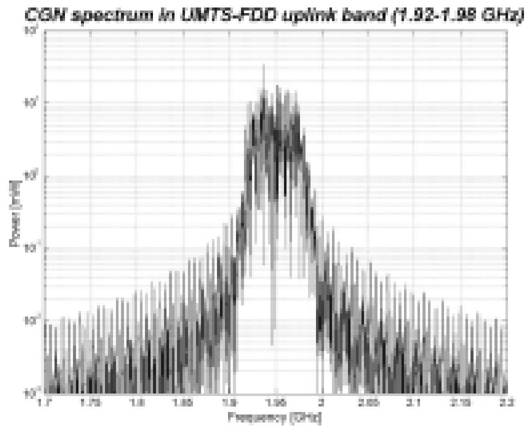


Figure 3. Spectrum of the coloured Gaussian noise located at UMTS DL band.

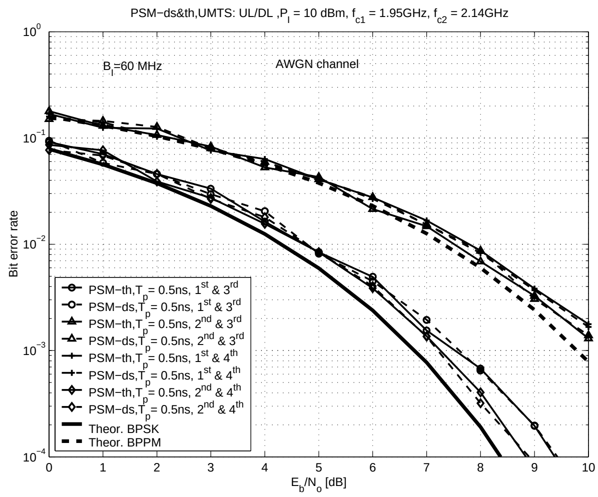


Figure 4. PSM modulated UWB system performances, T_p = 0.5 ns.

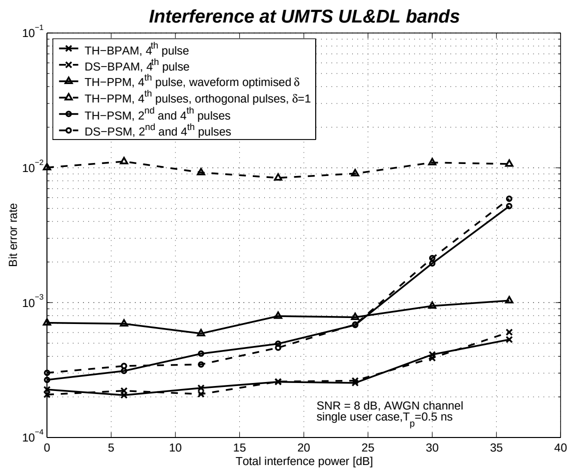


Figure 5. Bit-error-rates as a function of interference power, SNR = 8 dB.

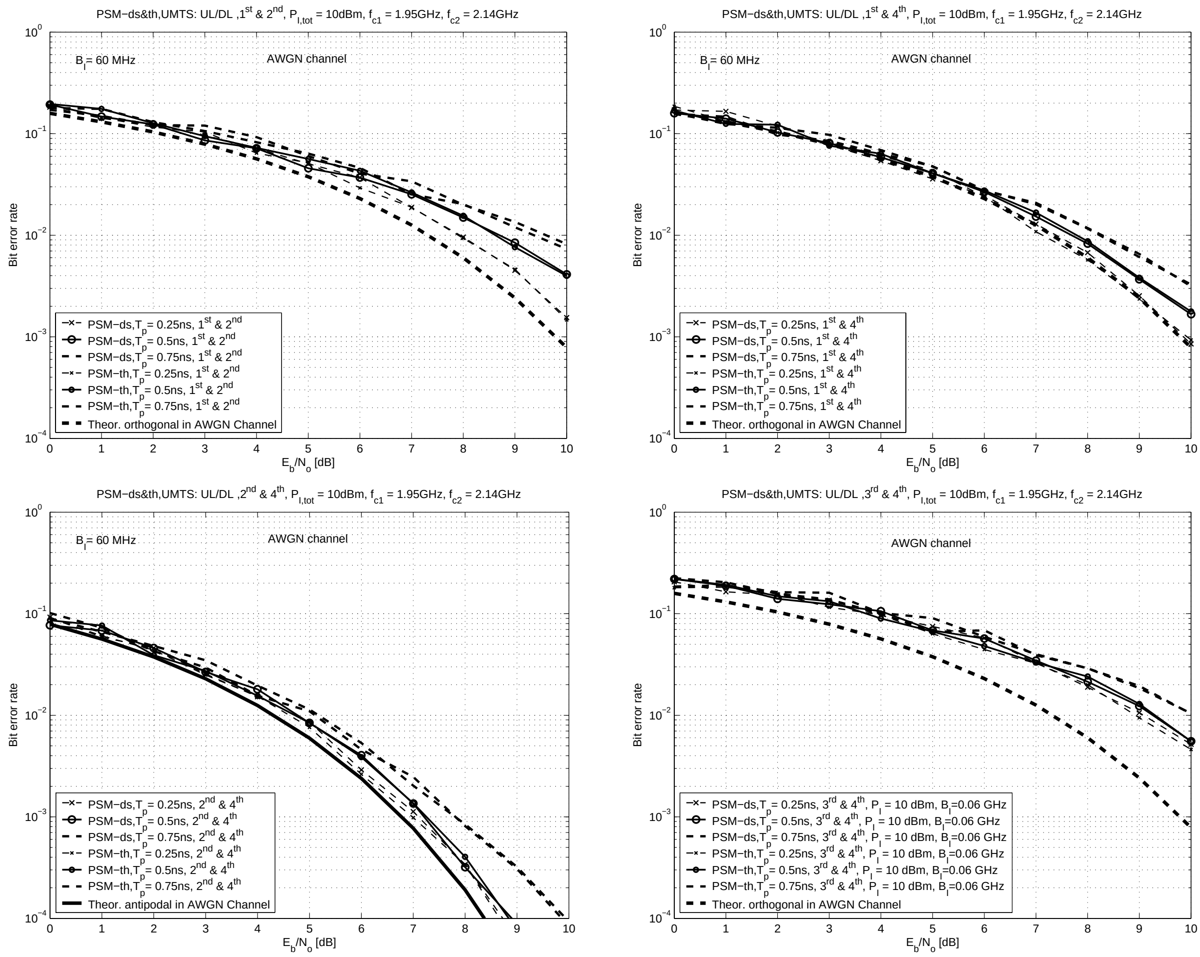
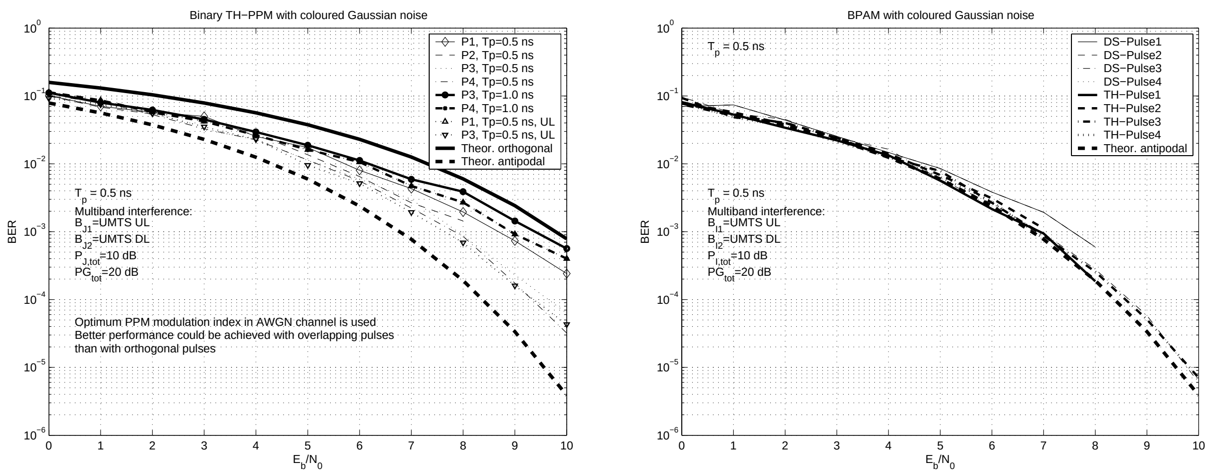


Figure 6. Performances of pulse shape modulated UWB systems with the presence of coloured Gaussian noise interference at UMTS uplink and downlink bands in AWGN channel. Different pulse pairs are used.



a) *b)*

Figure 7. Performances of PPM and PAM modulated UWB systems with the presence of coloured Gaussian noise interference at UMTS uplink and downlink bands in AWGN channel.