On the Performance Comparison of Different UWB Data Modulation Schemes in AWGN Channel in the Presence of Jamming

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ABSTRACT: *This paper studies performances of ultra wideband (UWB) communication systems in AWGN channel. The studied UWB systems are utilizing different kinds of modulation schemes. The propagating information signal is jammed with a signal having a spectrum in the UMTS or in the GSM band. The simulations showed that the time hopping UWB system utilizing binary PAM modulation outperforms the other studied modulation schemes in AWGN channel when jamming signal is present. The simulation results showed that the rank order of the studied modulation schemes in AWGN channel in the presence of jamming is time-hopping binary pulse amplitude modulation, direct sequence based binary pulse amplitude modulation, time hopping pulse position modulation and direct sequence based on-off-keying.*

1. INTRODUCTION

The baseband ultra wideband (UWB) system performances utilizing different modulation schemes in additive white Gaussian noise (AWGN) channel in the presence of pulsed jamming are studied. The UWB systems utilize time hopping (TH) and direct sequence (DS) concepts.

In TH-mode the pulse transmission instants are defined by a pseudo random (PR) code. One data bit is spread over the multiple pulses to achieve a processing gain due to the pulse repetition. The processing gain is also increased by the low duty cycle. In DS-mode a pseudo random code is used to spread data bit into multiple chips like in conventional DS spread spectrum systems still having a chip waveform causing UWB spectrum.

Data modulation schemes used in the study are binary pulse amplitude modulation (BPAM), pulse position modulation (PPM) and on-off keying (OOK). The BPAM is studied both in TH- and DS-modes, PPM is used in TH-mode and OOK in DS-mode.

In this paper the effect of the modulation scheme in the presence of jamming is discussed. The jamming bands in the study are about 2 GHz or less. The preliminary approval of UWB technology made by FCC [1] reserves the frequency band between 3.1 GHz and 10.6 GHz for indoor UWB communication systems. However, the difference between the modulation schemes in the presence of jamming can be found out also using smaller frequencies, as is the case in this paper.

The pulse waveforms used in the study are modifications of a Gaussian pulse having pulse widths smaller than 1.5 ns. The first four derivatives of the Gaussian pulse are used as radiated pulse waveforms. At the receiver the detection is based on the correlator where the template waveform is the first derivative of the radiated waveform. The derivation is based on the assumption that antenna is a high pass filter which differentiates the signals passing through [2]. The pulse jamming source used in the study has a spectrum located in UMTS bands and a multitone jamming source is located in GSM band.

2. MODULATION SCHEMES

2.1. Pulse position modulation (PPM)

Here follows a brief description of the implementation of binary pulse position modulation (PPM) in UWB systems. Due to this kind of modulation, the transmission interval between the consecutive pulses is varied according to the channelization code. Thus, the analytical expression of a time hopping (TH-UWB) transmitted signal using PPM can be written as follows [3]

$$s_{tr}(t) = \sum_{j=-\infty}^{+\infty} w_{tr}\left(t - jT_f - c_j T_c - (\delta T_p) d_j\right), \qquad (1)$$

where $w_{tr}(t)$ represents the transmitted UWB pulse waveform, T_f is the time length of a frame (pulse repetition interval), c_j is an element of the TH code sequence related to the j-th databit, T_c is the time interval unit used by the code to shift pulses from their equally spaced position and the databit sequence $\{d_j\}$ is composed by binary values “0” or “1”. Then, in order to implement the PPM modulation, symbols representing databit 1 are delayed of a time interval equal to δT_p, where δ is the modulation index which defines the time shift of databit “1”, and it is a fraction of the UWB pulse width T_p.

Figure 1 shows a particular case of PPM transmission where databit “1” is sent delayed by a fractional time interval $\delta < 1$ and databit “0” is sent at a nominal time defined by the pseudo random time hopping code. In this study PPM modulation is implemented only in time hopping UWB-system model.

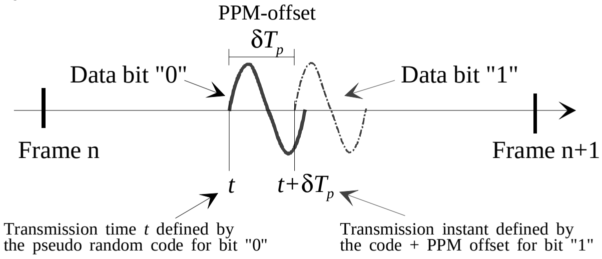

Fig. 1. A representation of TH-PPM concept.

2.2. Binary pulse amplitude modulation (BPAM)

The second modulation scheme used in the study is a binary pulse amplitude modulation. BPAM is used both in time hopping and direct sequence modes. DS-UWB mode is consistent with the conventional direct sequence spread spectrum systems but the chip waveform is a modification of a narrow Gaussian pulse. TH-UWB with BPAM mode follows the one presented in Chapter 2.1. In this case, the pulse or its amplitude-reversed version is sent. The pulse polarity depends on the data bit, and in DS-UWB, also on the chip polarity of the spreading code.

2.3. On-off keying (OOK)

The third modulation scheme studied in this paper is on-off keying. OOK is only implemented in DS-UWB mode. Firstly, the data bit is spread into multiple chips using binary pseudo random code like in DS-spread spectrum systems. Depending on the polarity of the code the pulse is sent ("1") or not ("-1"). Pulse waveforms remain the same as used in the previous modulation schemes.

3. JAMMING MODEL

In this study two different jamming signals have been used. Firstly, the jamming is located in the GSM900 uplink (UL) band (890 MHz - 915 MHz). Secondly, the jamming is located at the UMTS FDD[1] uplink band, i.e. between 1.92 GHz - 1.98 GHz [4].

The GSM jamming is generated using a multitone signal with total power P_I = +15 dBm. Tone assumption for GSM signal is valid due to the small GSM signal bandwidth B = 200 kHz that is a minor fraction of the UWB signal bandwidth. The tones are randomly spaced within the GSM band still keeping the physical channels 0 and 124 always allocated. The rest of the total 10 tones are reallocated as the signal to noise ratio changes. Besides, whenever the data bit changes the phases of the tones are randomly renewed.

The jamming in UMTS FDD band is modelled using signal energy evenly spread over the total 60 MHz UMTS frequency band. This approach assumes fully loaded UMTS band with total jamming power P_I = +10 dBm. The pulsed jamming is implemented using a sinc-waveform. The individual UMTS channels are not modelled since a continuous transmission in the whole band has been assumed.

4. PERFORMANCE OF TH-PPM IN AWGN CHANNEL

In PPM transmission, the parameter δ depicted in Section 2.1 can be considered as a free parameter whose value could be chosen in order to optimize the performances of the transmission system in terms of bit-error-rate (BER). When δ = 1, the PPM modulation is a canonical representation of orthogonal signals in AWGN channel. As a function of signal-to-noise-ratio (SNR), this leads to performances 3 dB worse than the case of antipodal ones, as is the case of, e.g., BPAM, already studied in previous work [5].

Figure 2 shows the performances of a TH-UWB system in terms of BER versus δ using PPM modulation for different pulse waveforms, as well as different pulse widths. The studied radiated pulse waveforms are the first four derivatives of a generic Gaussian pulse. As it can be noticed from the figure, for any choice of the transmission parameters, the absolute minimum of a BER in AWGN channel is dependent on a value of δ that is placed between 0.2 T_p and 0.3 T_p.

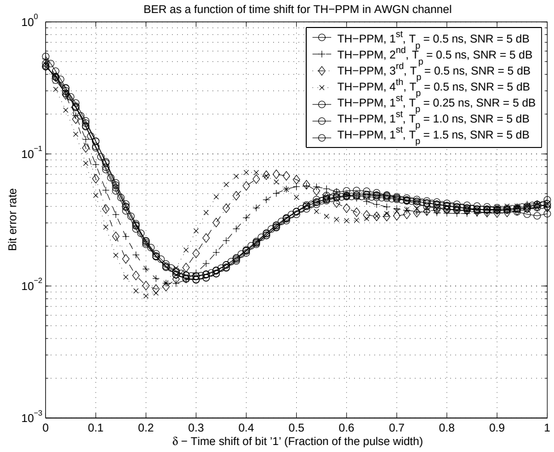

Fig. 2. BER as a function of δ in AWGN channel for different kinds of TH-UWB transmission systems with PPM modulation.

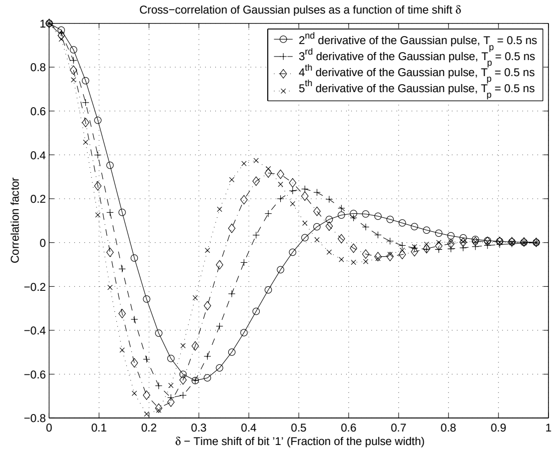

Fig. 3. Cross-correlation of different UWB pulses as a function of δ.

The use of the different pulse widths for the same pulse waveform (e.g., the first derivative of the Gaussian pulse in the figure) does not affect the BER. This can be justified noticing that δ is a fractional time shift related to the pulse width T_p. Thus, changing the length of the pulse, the relative position of the pulse for the databit "1" compared to the databit "0" remains the same.

On the other hand, as the order of the derivative increases, the minimum BER is reached for a lower value of δ, and the BER itself gives better results. The justification of this behaviour is related to the cross-correlation of the pulses related to the databits "0" and "1". Figure 3 shows the cross-correlation values for different kinds of pulses, related to the derivatives of the Gaussian one that are used when the results for Fig. 2 were calculated. There is no need to consider different pulse widths, since this does not affect the results related to the different values of δ, as previously mentioned. Besides, for a fair comparison, the received waveforms have been considered. This means that the BER performances

[1] FDD = Frequency Division Duplex

shown in Fig. 2 have to be compared with their first derivatives in Fig. 3, in the assumption of considering the receiving antenna acting as a high-pass filter (differentiator) [2].

Two main peculiarities have to be pointed out for PPM:

- The cross-correlation of these Gaussian-related waveforms gives negative values as well. This justifies the possibility to outperform the probability of error of orthogonal signal that have cross-correlation equal to zero ($\delta = 1$, orthogonal signals, in Fig. 3).
- The cross-correlation absolute minima are reached exactly for those δ's where the BER gives the better performances.

As a matter of fact, the behaviour of the cross-correlation gives a method of choice for the parameter δ in AWGN channel. Besides, it can be fixed *a priori* once the pulse waveform characterizing the UWB transmission is chosen. The best value for δ can be selected once the minimum of the cross-correlation of the pulse waveform is calculated. Afterwards, the optimum value for δ is used when PPM modulation is studied. The optimal δ's for the used pulse waveforms are presented in Table 1.

Table 1. Optimal time shifts δ for PPM modulation in AWGN channel for the used radiated waveforms.

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

5. SIMULATION RESULTS

In this chapter the simulation results for the UWB system performances in AWGN channel in the presence of jamming are given. Bit error rates are studied as a function of signal-to-noise-ratio and as a function of jamming-to-signal-ratio.

During the simulations the signal power is fixed to 0 dBm and the UWB system's processing gain is fixed to 20 dB. In TH-mode, 10 dB of the total processing gain is coming from the low duty cycle, and 10 dB from the pulse integration (pulse repetition). The processing gain in DS-UWB comes only from the pulse integration. When BER is studied as a function of jamming-to-signal-ratio, the SNR is fixed to 8 dB. The simulated bit-error-rates are referred to the theoretical limits of a corresponding modulation scheme. According to the theoretical values, the performance of BPAM is 3 dB better than the performance of PPM and OOK. The upper bound limits for BPAM, 2-level PPM and OOK can be defined as [6]

$$P_{e,BPAM} = Q\left(\sqrt{2\frac{E_b}{N_0}}\right) \text{and } P_{e,PPM} = P_{e,OOK} = Q\left(\sqrt{\frac{E_b}{N_0}}\right), \quad (2)$$

where E_b is the signal energy and N_0 is the noise power spectral density.

5.1. GSM jamming

In this chapter the UWB system performances based on different modulation schemes are studied when the interfering signal is modelled as a multitone jamming in GSM uplink band. The total jamming power is P_I = -15 dBm. All the studied radiated pulse waveforms are related to the 1st derivative of the Gaussian pulse. Figures 4a and b represent the bit-error-rates as a function of signal-to-noise-ratio. The UWB signal power is fixed to 0 dBm. In Fig. 4a the modulation scheme used is BPAM, and in Fig. 4b OOK and PPM are used, respectively. As one can notice, in the presence of jamming the UWB system performance depends on the pulse width and the implemented modulation scheme. Without interfering signal all the curves reach the theoretical curve. Comparing the results where BPAM modulation is used one can notice that TH-UWB outperforms corresponding DS-UWB. The difference between TH-BPAM and TH-PPM is typically less than 1 dB for the benefit of BPAM. DS-OOK gives the worst performances.

5.2. UMTS jamming

Corresponding BER simulations as a function of SNR with a pulsed sinc-signal having a spectrum in UMTS FDD-UL band are represented in Figures 5a and 5b. The studied radiated pulse waveforms are related to the 1st derivatives of a Gaussian pulse. In BER point-of-view the rank order for the different UWB concepts is TH-BPAM, DS-BPAM, TH-PPM and DS-OOK. This is valid for all the pulse widths used.

In Figures 6a and 6b bit-errror-rates are presented for the first four Gaussian derivatives as a function of jamming-to-signal-power-ratio. As one can notice from the figures, the OOK is the most sensitive for the jamming. The difference in performances of BPAM and PPM is not so significant. However, BPAM based system still outperforms PPM based system. TH-BPAM gives slightly the best performance, and the difference between DS-BPAM and TH-PPM is about 1 dB. When the jamming-to-signal ratio increases also the system performance degradations will reach the same values. Moreover, when the pulsed jamming overlaps the nominal center frequency of the UWB signal there can not be found any significant difference from the results.

6. CONCLUSION

In this paper the effect of the different modulation schemes to the UWB system performance is studied in AWGN channel in presence of jamming signals. The selection of the data modulation scheme in UWB system defines also the jamming tolerance. The simulation results showed that the rank order of the studied modulation schemes in AWGN channel in the presence of jamming is TH-BPAM, DS-BPAM, TH-PPM and DS-OOK. This rank is valid for both studied jamming cases: multitone jamming in GSM band and pulsed-sinc having a spectrum in UMTS band.

7. ACKNOWLEDGEMENTS

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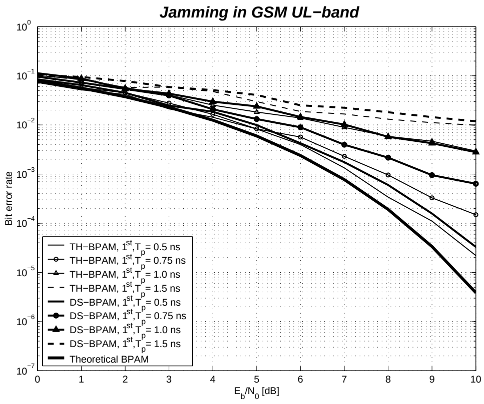

Fig. 4a. BER as a function of signal-to-noise ratio for TH-BPAM and DS-BPAM when jamming is in GSM UL.

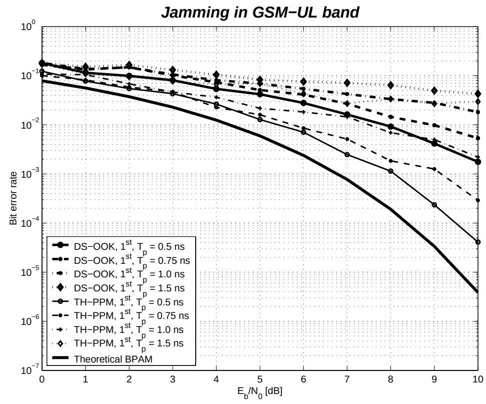

Fig. 4b. BER as a function of signal-to-noise ratio for TH-PPM and DS-OOK when jamming is in GSM UL.

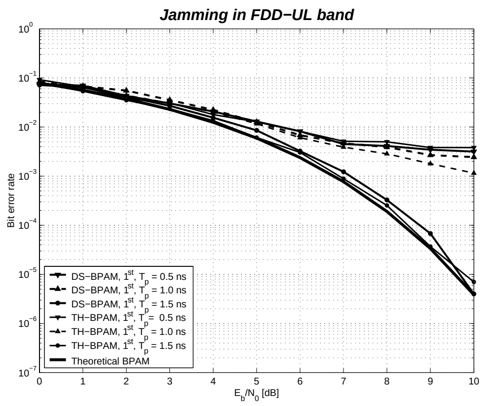

Fig. 5a. BER for TH- and DS-BPAM based UWB systems with four pulse widths. Jamming is in UMTS FDD-UL band.

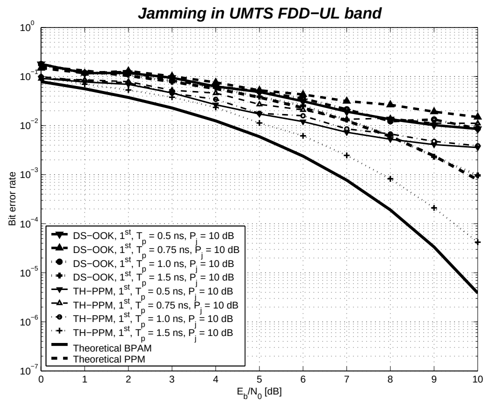

Fig. 5b. BER for DS-OOK and TH-PPM based UWB systems with four pulse widths. Jamming is in UMTS FDD-UL band.

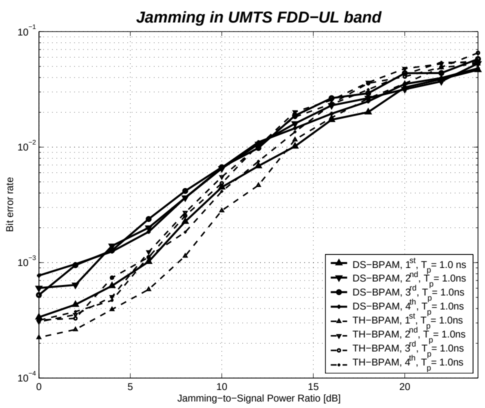

Fig. 6a. BER as a function of jamming-to-signal-ratio for the first four derivatives of a Gaussian pulse. Data modulation is BPAM.

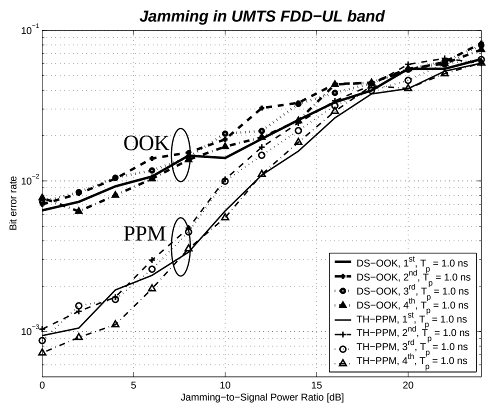

Fig. 6b. BER as a function of jamming-to-signal-ratio for the first four derivatives of a Gaussian pulse. Data modulations are PPM and OOK.