Optimization of DWT parameters for jamming excision in DSSS Systems

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Abstract: Direct Sequence/Spread-Spectrum (DSSS) is a commonly used communication technique for civilian and military applications. DSSS signals are characterized by wide bandwidth and a low power spectral density. Despite DSSS is very robust respect to the jamming, if jamming signals are high with respect to the Process Gain (G_P) some techniques must be introduced for guaranteeing a good link performance [2]. For this reason modern satellites are equipped with an anti-jamming system [10]. In this paper the use of the Discrete Wavelet Transform (DWT) for the jamming detection and excision is analyzed. Experiments are performed considering the commonly used jammers types.

Key–Words: Jamming Excision, Wavelet Packet Decomposition, DSSS, DWT, Daubechies.

1 Introduction

Spread Spectrum techniques spread band-limited signals in the whole frequency domain resulting in a signal with a wider spectrum. Such techniques have several aims and are widely used to prevent signal detection and to increase the resistance to noise and jamming. However if the jamming signals power is greater then the Process Gain (G_P), the jamming mitigation cannot be realized. In these cases jamming excision techniques are required. There is a wide variety of techniques that supplement the inherent ability of a spread spectrum system to reject narrow-band interference ([4], [3]). Generally, they exploit the spectral difference between the narrow-band interference and the wide-band of spread spectrum signal.

Most of these techniques are not able to deal with multi-tone jamming [10]. In literature there are different works dealing with the development of flexible and adaptable anti-jamming techniques ([1], [3], [4]). Among these techniques a great interest is oriented toward the development of anti-jamming system based on the Wavelet Transform[9]. In the literature there is a lack of complete analysis about the optimization of the wavelet parameters. In this paper the authors analyze the impact of these parameters on the performance of the anti jamming systems for Direct Sequence Spread Spectrum (DSSS) transmission. The analysis has been developed through extensive simulations where the impact of the following parameters have been studied: mother wavelet choice, decomposition level, filter latency and number of mother wavelet samples.

2 Jamming

The action of a jammer consists to disturb a radio communication using active signals. The jamming is mostly used in electronic warfare, and, together to the deception and the direct energy, is one of the main strategies of electronic attacks. The jamming reduces the information availability slowing down the communication process. Due to the jamming information can be useless for a certain time. The jammer can be modeled in different ways. Some types of narrow-band jamming are listed below:

- Tone Jamming
- Pulse Jamming
- Swept Jamming
- Hop Jamming

The common approach used to split the signal from the jammer lies in the excision of the portion of spectrum where the interference is located (see Fig.1). In this paper the jamming excision is performed using the *Discrete Wavelet Transform* [8].

3 Discrete Wavelet Transform

The discrete wavelet transform is a linear time-frequency-transformation used to represent a function in another domain, generally used for analysis.

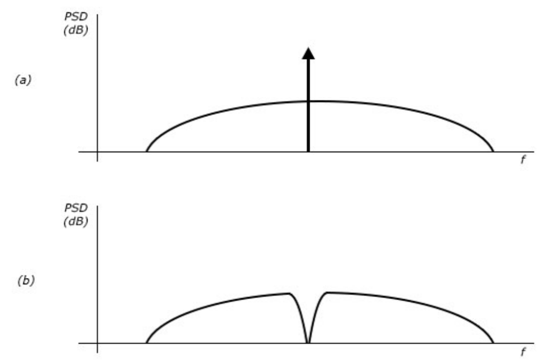

Figure 1: DSSS spectrum: (a) in presence of jammer, (b) after excision

As the Fourier transform, in order to correlate a signal with a sinusoidal waveform, the wavelet transform correlates the signal with a finite length waveform called *mother wavelet*, appropriately scaled and translated. With wavelet transformation it's possible to obtain a new representation domain comparable to the time-frequency domain of a Short Time Fourier Transform (STFT). According to [5], a signal can be transformed in time-frequency space using a Wavelet Packet Tree. Assuming N levels of the tree, the result of the Wavelet Packet Tree is composed of 2^N channels, where each one represents a portion of the signal in time. It's also called *Wavelet Packet Decomposition* (WPD). This operation can be reversed using an inverse Wavelet Packet Tree. Each couple of branch is filtered by another pair of conjugate mirror filters after the up-sampling by a factor of two and then added. The final signal is the perfect reconstruction of the original signal. A wavelet decomposition could be used to excise a jammer from a *DSSS* signal [9]. The strategy used to reject the jammer, based on the wavelet transform, is shown in Fig.2. Through *Wavelet Packet Decomposition* any signal can be split in 2^N sub-bands, with N the number of decomposition levels. Integrating each sub-band it's possible to obtain the energy of a part of the spectrum of the starting signal. Therefore, the noise will be in the sub-band whose the energy exceeds an certain threshold. Each sequence of a sub-band where the jammer was located is erased with multiplication by zero. Finally the signal is reconstructed by a *Wavelet Packet Reconstruction* (WPR), that is the opposite operation of WPD.

In the following sections the authors analyze the impact of the wavelet parameters on the anti-jamming system performance. The analysis is based on an extensive MATLAB simulations which allow the evaluation of the impact relative to the following parameters: mother wavelet choice, decomposition level, filter latency and number of mother wavelet samples.

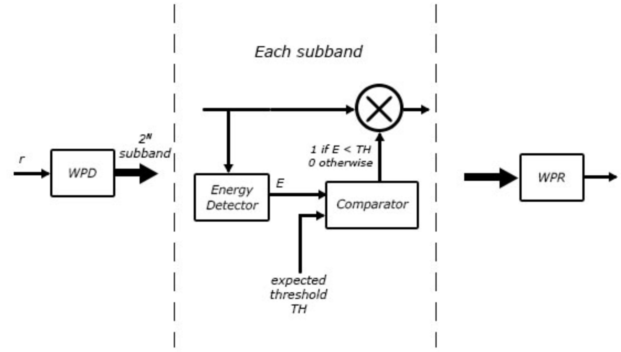

Figure 2: Wavelet strategy for jamming rejection

4 Simulation Setup

The simulations were performed following the steps below:

- Generation of BPSK modulated signal,
- Signal spreading using DSSS technique,
- Generation and addition of the jamming to the DSSS signal,
- Subband decomposition using WPD,
- Subband energy estimation for jamming detection (see Fig. 2),
- Erasing of the sub-bands affected by the jamming,
- Reconstruction of the signal using the WPR.

A suitable simulation scenario was chosen in order to simulate a satellite communication like environment. This is one of the field with the highest necessity of reliable communication. The following are the default parameters for the simulations, except where differently specified. They are defined taking into account the definition of the Process Gain in eq.1

$$G_p = \frac{T_b}{T_c} = \frac{R_c}{R_b}, \tag{1}$$

where T_b is the period of the bit,T_c is the period of the chip and R_c and R_b are the rates of the chip and the bit respectively.

The carrier frequency was chosen equal to $10MHz$ and sampling frequency was set to $40MHz$. Choosing a chip rate of $2Mchip/s$ and a bit rate of $16Kb/s$, a *process gain* $G_p \simeq 21dB$ is obtained. With a *Jammer-to-Signal Ratio* $JSR = 30dB$ the probability of having a wrong bit is $P_2 = 0.31$ [7]. Under this condition is not possible to have a reliable communication without any denoising process. Furthermore a lot of communication links require an error probability less then 10^{-6}. The simulation length was of 40000 points corresponding to a simulation time of $Ts = 0.01s$ and 160 bits sent. For *single tone* jamming were considered 3 different jamming tones near the carrier frequency: $F_j^I = 9.95MHz$, $F_j^{II} = 9.90MHz$ and $F_j^{III} = 10.15MHz$. The period of *pulsed jamming* was set to $1ms$ with a duty cycles of 25% ($250\mu s$). The *swept jamming* was simulated with a linear sweep from $9.75MHz$ to $10.25MHz$. The *hop jamming* casually changed his frequency in a range from $9MHz$ to $11MHz$ with a frequency hop $F_h = 4KHz$. In order to speed up the simulation the Bit Error Rate (BER) was estimated using the semi-analytic method proposed in [6].

4.1 Wavelet Packet Decomposition

Using *Wavelet Packet Decomposition* (WPD) some parameters could be optimized in order to minimize the BER value and consequentially maximizing the performance. In particular in this section the following parameters are considered: *mother wavelet* (see 4.1.1), *level of decomposition* (see 4.1.2), the *number of coefficients* (see 4.1.3) and *length of energy integration interval* (see 4.1.4). Since the behavior of WPD for swept and hop jamming can be derived from single and multi-tone analysis, their simulation results are omitted for the choice of the first parameter. On the other hand since WPD behavior is greatly dependent on the delay of the structure, swept jamming has been analyzed for choosing the decomposition level, the number of coefficients and the length of energy integration interval.

4.1.1 Mother Wavelet

The first step is the selection of a proper *mother wavelet* that can be used in WPD. Several simulations were performed in order to determinate the most suitable mother wavelet for jamming rejection among the three best known in literature: Daubechies, Coiflet and Symlet. Fig.3 and Fig.4 represent the BER as a function of the parameter $\frac{E_b}{N_0}$ respectively for a *tone jamming* and *pulsed jamming* using the above mentioned mother wavelets: Daubechies (blue lines), Coiflet (red lines) and Symlet (green lines).
The study of the BER doesn't highlight a real difference between the mother wavelets proposed. In both graphs the curve are very close. Taking into account the above results and considering the greater availability and use in literature of the *Daubechies* wavelet, all

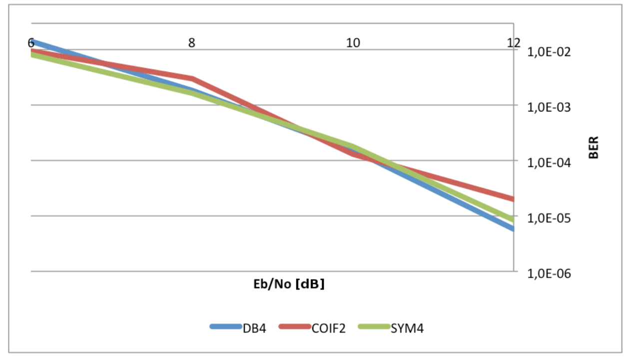

Figure 3: *Tone amming* rejected using Daubechies, Coiflet and Symlet mother wavelets.

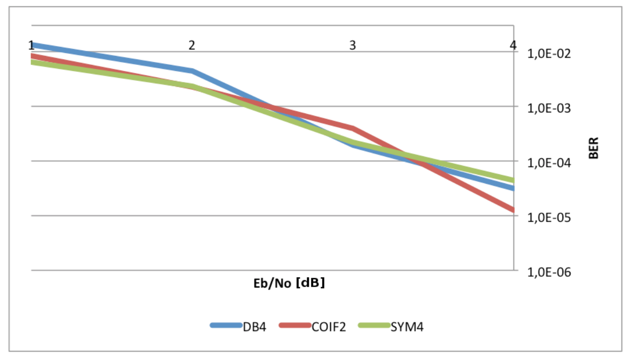

Figure 4: *Pulse jamming* rejected using Daubechies, Coiflet and Symlet mother wavelets.

the experiments are carried out using this wavelet family.

4.1.2 Level of decomposition

After the determination of the wavelet family, the next parameter considered in the study is the level of decomposition (N). The comparison is performed using the same approach. Using *Daubechies* (*db4* where 4 is the filter order) as mother wavelet, different values of N were tried. The input signal was added to a tone jamming (see Fig.5) and a pulsed jamming (see Fig.6). Simulations showed a progressive improvement in the BER value increasing the number of the level of decomposition N. After a certain value of N, curves show a saturation of BER improvement (see Fig.5 and Fig.6) that in some cases leads to a performance degradation.

This behavior can be justified analyzing the WPD in frequency as function of N. Increasing the value of N the single sub-band narrows, therefore less portion of band, where the signal is contained, will be removed. On the other hand, each sub-band cannot be narrow as required, due to the filter selectivity used in WPD associated to *db4*. This explains because, after a specific value of N, the BER value stops to decrease. Using a wavelet with higher order filter, as

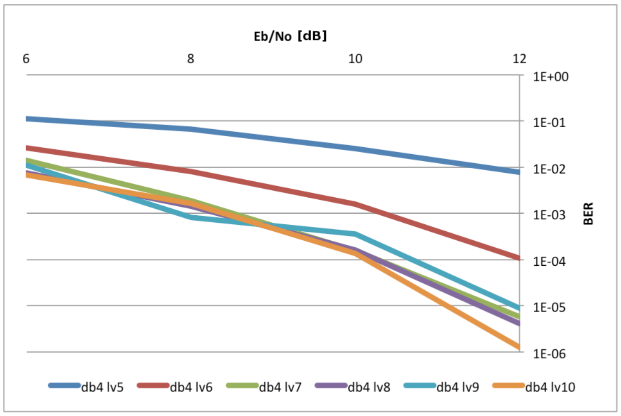

Figure 5: *Tone jamming* rejected by Daubechies 4 wavelet method using different levels of decomposition.

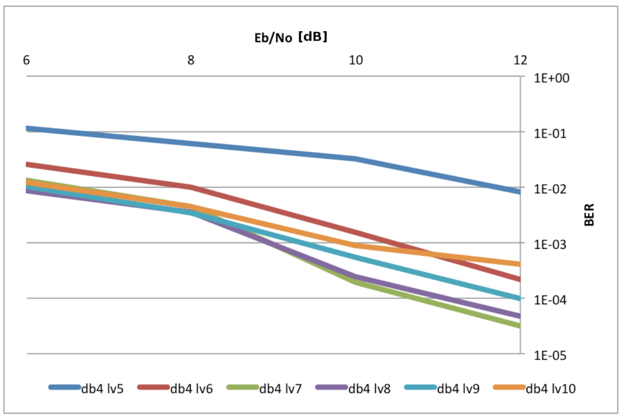

Figure 6: *Pulsed jamming* rejected by Daubechies 4 wavelet method using different levels of decomposition.

Daubechies 20 (*db20*), the limit level increases (see Fig.7), achieving better performance at expense of a greater computation complexity. For swept jamming the *number of coefficients* Vs *decomposition levels* for 8, 9, 10 are shown respectively in Figures 14, 13 and 10. This point will be discuss further in the section 4.3.

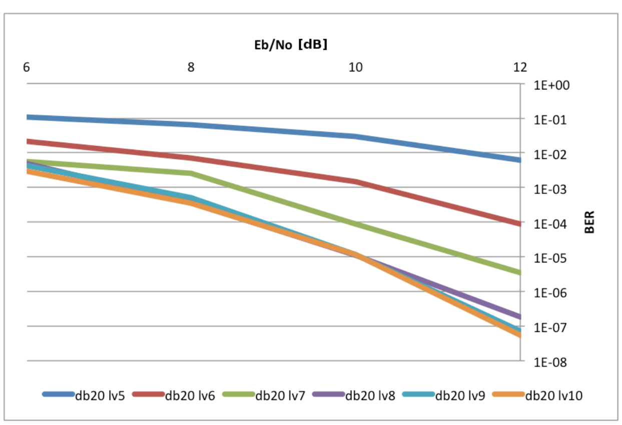

Figure 7: *Tone jamming* rejected by Daubechies 20 wavelet method using a high order filters.

4.1.3 Number of Coefficients

In the WPD for a given wavelet family, the mother wavelet can be represented with a different number of samples. Higher it's the number of the samples, higher it's the time delay of the filter. Moreover since the computational complexity grows with the number of coefficients, the aim is to minimize it.

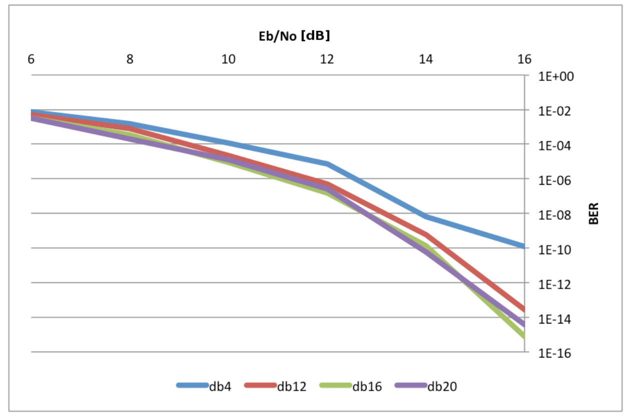

Figure 8: *Tone jamming* rejected by Daubechies wavelet method using different number of coefficients.

In Fig.8, Fig.9 and Fig.10 the level of decomposition was fixed to 10 and different number of coefficients were used and are represented in the graph by a different curve. The jammers used to disturb the input were: a tone jamming (Fig.8), a pulsed jamming (Fig. 9) and a swept jamming (Fig. 10).

In the case of tone jamming the BER curves shift down decreasing until the value reached by wavelet *db16*, this result is very similar also for wavelet *db20*. The increase of the number of coefficients improves the selectivity of the filter used by WPD, improving therefore the frequency resolution. If the input is added to a pulsed jamming this effect is compensated by a worse time resolution. Consequently the obtained result is a series of very close curves.

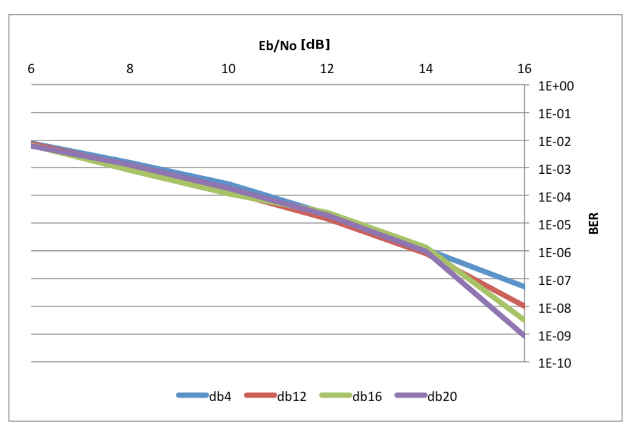

Figure 9: *Pulsed jamming* rejected by Daubechies wavelet method using different number of coefficients.

Using a swept jamming the worsening of time resolution is predominant. The obtained values using a *db16* and *db20* are even worse then using *db12*. This type of jamming will be discuss further in sec. 4.3.

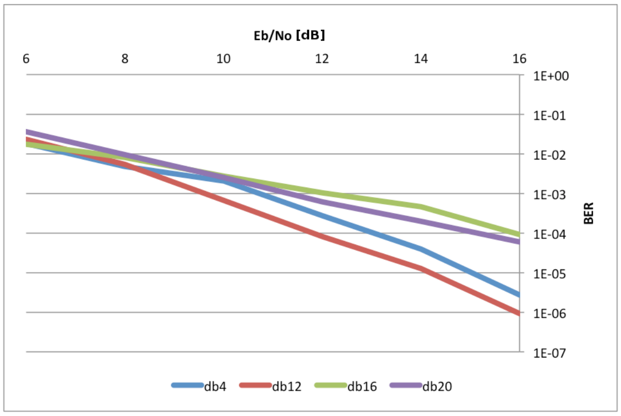

Figure 10: *Swept jamming* rejected by Daubechies wavelet method using different number of coefficients and 10 levels of decomposition.

4.1.4 Length of energy integration interval

As mentioned above (see Sect.3), there is an energy detector which integrates the signal of each sub-band. For allowing real-time operations, the integration time cannot be too long. A time variant jammer, like *swept jamming*, spread the energy in different sub-bands during operation.

In order to promptly capture the temporary presence of jamming in the sub-band, a short integration time would be required. But decreasing the interval of integration, can make the detector more sensitive to noise. Consequently, even in the event of jamming presence, the energy level may be so low (with respect to the threshold) to prevent its detection.

The shorter time interval for obtaining a reasonable output is the delay time of the WPD equivalent filter. To evaluate this time, the WPD was stimulated by a single tone and the output of the sub-band corresponding to the tone was considered. Stimulating the system with a 10MHz tone, the output of 33rd sub-band has the trend shown in Fig.11. therefore the result has a continuous signal.

In Table 1 the delay time for different WPD parameters is reported. These delays are evaluated using the same strategy illustrated above. The energy integration times used in final system double those of Table 1.

4.2 Excision with Multitone Jamming

For multitone Jamming, experiments are performed considering the sinusoidal signals discussed in Sec. 4. A decomposition level of 10 and 20 coefficients

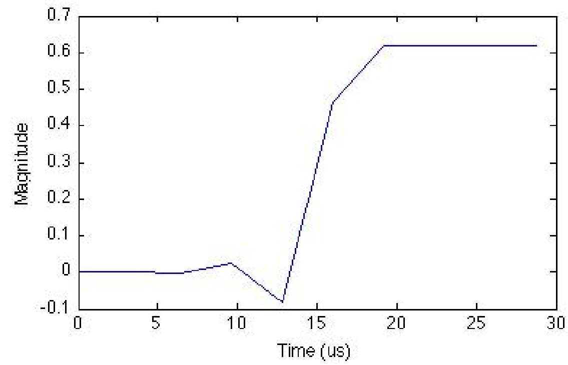

Figure 11: Output of the 33rd sub-band of a WPD with a 10MHz tone as input and with *db4* as wavelet function.

Table 1: Delays measured at the output of a WPD with a 10MHz tone as input.

	Wavelet				
N	*db4*	*db12*	*db16*	*db20*	*db30*
7	19.2us	67.2us	89.6us	112us	169.6us
8	38.4us	134.4us	179.2us	224us	339.2us
9	76.4us	268.8us	358.4us	448us	678.4us
10	152.8us	536.6us	716.8us	896us	1356.8us

(as discussed in Section 4.1.3) represent the optimal choice.

Simulation results are shown in Fig.12. Estimation is performed comparing the BER curve obtained in absence of noise with the BER curve obtained in the case of signal jammed with one, two or three tones.

The results indicate that for multitone Jamming the excision algorithm gives worst results than a single tone jamming.

This is because in the case of multi-tone jamming the jamming components can be located in different sub-bands and consequently more channels are suppressed by the algorithm.

In general, a greater number of suppressed bands implies a decrease of the useful-signal energy.

4.3 Excision with Swept Jamming

In presence of a sweep jamming, the jammer signal can move across different sub-bands. In order to be detected, the jamming signal must remain within a channel for a time greater then the length of energy integration interval (see Sect.4.1.4). In addition the system latency must be small enough to allow the detection of the jamming without compromising real time. Since the latency depends on the number of coefficients and the level of decomposition (for each level of decomposition a proper filter is required), the simulations are performed considering these parameters.

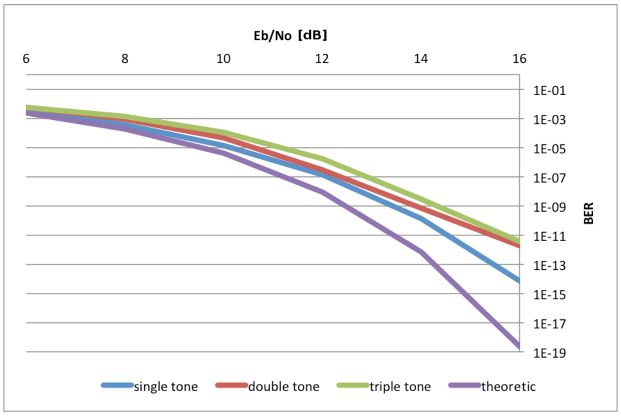

Figure 12: *Multi-tone jamming* rejected by wavelet method

The number of coefficients considered in simulations is 4, 12, 16 and 20 meanwhile the levels of decomposition are 8 (Fig.14), 9 (Fig.13) and 10 (Fig.10). Simulation results show that it's possible to obtain a BER value less than 10^{-8} using 9 levels of decomposition and a db16 or db20 wavelet with a $\frac{E_b}{N_0} = 16dB$.

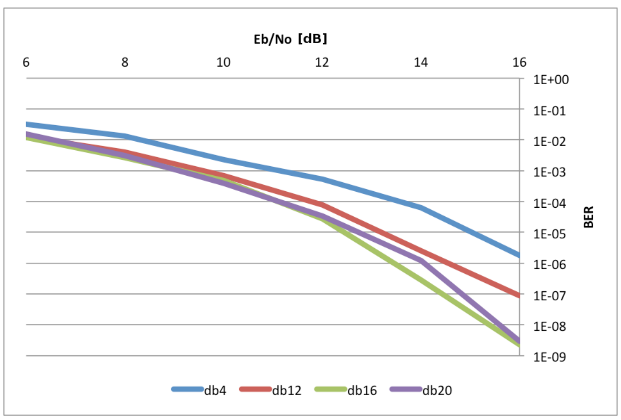

Figure 13: Swept jamming rejected by wavelet method usign 9 levels of decomposition

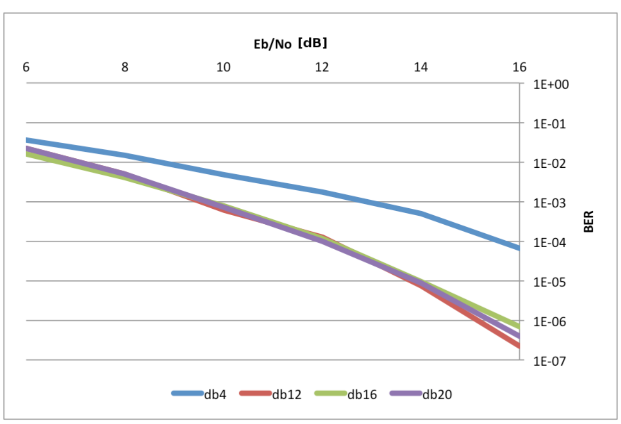

Figure 14: *Swept jamming* rejected by wavelet method usign 8 levels of decomposition

4.3.1 Excision with Hop Jamming

When Hop Jamming is involved the most important parameter is the length of the energy integration interval. In facts in order to assure the jamming detection this time must be comparable with the hopping time. Simulation are performed considering 10 levels of decomposition and a db16 wavelet that are the optimal choice for single tone jamming (hop jamming can be considered a particular case of single tone jamming). Simulation results are shown in Fig.15 considering integration intervals of $716.8\mu s$

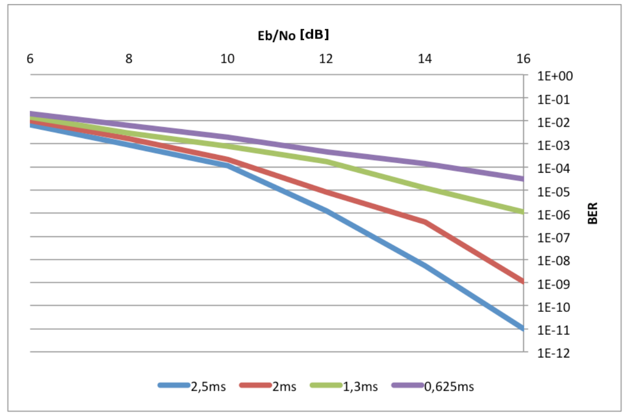

Figure 15: *Hop jamming* rejected by db16 wavelet method using 10 levels of decomposition.

5 Conclusion

n this paper the use of the DWT for the jamming detection and excision has been analyzed. The analysis has been performed in order to evaluate the impact of the wavelet parameters (mother wavelet choice, decomposition level, filter latency and number of mother wavelet samples) on the excision performance for different types of jamming.

Experimental results confirm that the wavelet transform can be used effectively to mitigate the effects of tone and multi-tone jamming, pulse jamming, hop jamming and swept jamming.

Furthermore, the present work shows that the effectiveness of this method is dependent on the parameters used for the design of the wavelet structure. Each parameter has a different effect on the system performance.

For example, the simulation results indicate that the different mother wavelet show a similar behavior. Consequently, their choice is not so critical.

On the other hand, if we consider the other parameters their impact on the jamming excision performance also depends on the kind of jamming considered.

Let consider the pulsed and swept jamming, the excision performance decreases with the decrease of the wavelet time resolution. For this reason the performance deteriorates with the increase of the number of decomposition levels and with the number of coefficients used in wavelet representation.

Analyzing the obtained results, for each jamming type it is possible to select a set of suitable parameters. These parameters are summarized in (Tab.2).

Table 2: Chosen parameters for wavelet method

Parameters	*Single-tone, multi-tone and pulse jamming*	*Swept jamming*	*Hop jamming*
Wavelet	db20	db16	db16
N	10	9	10
Time	896us	358,4us	716,8us

The parameters are obtained as a trade-off among the different aspects (performance, implementation complexity, ...).

In future works, it could be useful to compare the wavelet transform with other time-frequency analysis methods, as the Short Time Fourier Transform (STFT) or the Perfect Reconstruction Polyphase Filter Bank.

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