Interference excision in DSSS based on the Undecimated Wavelet Packet Transform

Emilia Pardo, Juan J. Pérez, and Miguel A. Rodríguez

Abstract: This article presents an algorithm for suppressing narrowband interference in Direct-Sequence Spread-Spectrum Systems. It is based on a combination of frequency shifts with the Undecimated Wavelet Packet Transform. Simulation results show very robust and nearly optimal performance.

Introduction: The interference rejection performance of a spread spectrum communication system can be improved by interference suppression techniques. The case of a Direct-Sequence Spread-Spectrum (DSSS) waveform received in the presence of narrowband interference is considered in this article. Transform domain excision is a suitable approach for interference suppression. Among the different transforms, those based on wavelet packets, which are intimately related to hierarchical filter banks [1, 2], have been shown to be especially useful. In particular, the adaptive hierarchical Tree Structuring Algorithm (TSA) proposed in [2] yields superior performance in comparison to conventional fixed transforms. The performance of the TSA depends on the position and bandwidth of the interference. In this article we propose an algorithm for interference excision in DSSS systems, based on the Undecimated Wavelet Packet Transform (UWPT) with performance independent of the interference frequency. It has been previously applied with success to FHSS systems [3].

The system considered is a coherent DS/BPSK [2][4] with narrowband interference and AWGN, thus the received signal is:

$$\mathrm{r(t) = c(t)d(t)\sqrt{2S}\cos(w_0 t) + I(t) + n_w(t)} \qquad (1)$$

being $d(t)=d_m$, $mT_b \leq t \leq (m+1)T_b$, $d_m \in \{-1,1\}$ the data sequence and $c(t)=c_n$, $nT_c \leq t \leq (n+1)T_c$, $c_n \in \{-1,1\}$ the pseudo-noise sequence. T_b is the bit time and T_c is the chip time interval. $K=T_b/T_c$ is the spreading factor. The receiver scheme is shown in Fig. 1.

UWPT exciser: This is based on the application of frequency shifts to the signal in order to place the interference inside of one of the pass-band filters. Since the intervals in the UWPT expansion become smaller as resolution increases (Fig. 2b), the algorithm will begin with the highest resolution level to reduce the number of possible frequency shifts. Due to the fact that the transition and the pass-band intervals in successive resolution levels are aligned (see Fig. 2b), once the optimum frequency shift is obtained at the highest resolution level, the interference will remain centred at the other levels just by shifting either 0 or $B_j/2$, where B_j is the bandwidth of subbands at level j. Therefore, there is no longer any need to try with all possible frequency shifts.

The following is a description of the UWPT exciser. Let J be the highest resolution level. For each $d(J) \in [0,\ldots,B_J]$ with step Δd, the following actions are performed:

1. The input vector is frequency shifted.
2. It is then filtered to obtain the low- and high-pass subbands, $W_{J,0,d(J)}$ and $W_{J,1,d(J)}$. The filters for a generic level j are defined as:

$$H_{0j}(z) = H_0(z^{2^{j-1}}) \qquad H_{1j}(z) = H_1(z^{2^{j-1}}) \qquad (2)$$

   where $H_0(z)$, $H_1(z)$ are the 2-band prototype analysis filters.

3. Finally, the energy difference between both subbands is calculated:

$$\Delta E_{J,d(J)} = \left\| \sum_{n=0}^{N-1} \left\| W_{J,1,d(J)}(n) \right\|^2 - \sum_{n=0}^{N-1} \left\| W_{J,0,d(J)}(n) \right\|^2 \right\| \qquad (3)$$

When the interference is centered, $\Delta E_{J,d(J)}$ reaches its highest value, so the optimum frequency shift can be obtained as $D(J)=\{d(J)|\max(\Delta E_{J,d(J)})\}$. Between the corresponding subbands, $W_{J,0,D(J)}$ and $W_{J,1,D(J)}$, the one with the greatest energy contains the interference, thus it is chosen as the new input vector X_{J-1} for the next resolution level. The other subband is saved together with D(J) for the reconstruction. If the values of $\Delta E_{J,d(J)}$ are all under a certain threshold, the interference cannot be totally contained in a single subband at level J, and therefore the algorithm must start at level J-1.

At the remaining levels $j \in [J-1,\ldots,1]$ the procedure is basically the same, but there is no need to apply all possible frequency shifts because the optimum one is known beforehand: D(j)=0 if X_j comes from $W_{j+1,0,D(j+1)}$ and D(j)=$B_j/2$ if X_j comes from $W_{j+1,1,D(j+1)}$.

Finally, when level "1" is met, the X_0 vector, which concentrates the interference, is removed. At this step, the synthesis process begins using the saved vectors, from resolution level "1" until "J". At each level, the frequency shift is undone to restore the interference-free original signal.

Results: The DS/BPSK system described above (Fig. 1) was simulated. Both the UWPT and TSA excisers were implemented in order to compare their performances. Two types of narrowband interferences were considered: a single tone and a narrowband Gaussian interference with 10% bandwidth. In both cases we assumed a signal-to-interference power ratio of -20 dB and a spreading factor of K=63 chips per bit were selected.

Fig. 3a displays the bit error rate (BER) performance for a single tone interference with frequency $\omega=0.587\pi$ radians and uniformly distributed random phase. The UWPT curve shows nearly optimal performance and it is slightly better than the TSA results due to the limitations of TSA with the interferences closed to the transition zones. Fig. 3b shows the results for a narrowband Gaussian interference affecting 10% of the spread signal bandwidth and centred around two frequencies: $\omega_1=0.06\pi$ radians and $\omega_2=0.527\pi$ radians. The latter is also illustrated in Fig 2.

The UWPT exciser obtains the same performance for both frequencies while the TSA results vary with the frequency. For the ω_1 case (0.06π) the results are the same for both methods. While, for the ω_2 case (0.527π) the result of UWPT method is the same but the result of TSA method is of little value due again to the limitation of this method in the transition zones.

Thus, the UWPT algorithm obtains results similar to the TSA algorithm and the performance is constant with the interference frequency location.

Conclusions: We propose a new algorithm for narrowband interference excision in DS-SS systems. By applying frequency shifts along with the UWPT, the interference energy is confined in the pass-band filters frequency intervals. Thus the interference is eliminated with no significant loss of signal energy. The experiments show that the algorithm tracks the variations of the input signal and provides a very robust performance with independence of the interference frequency location.

References

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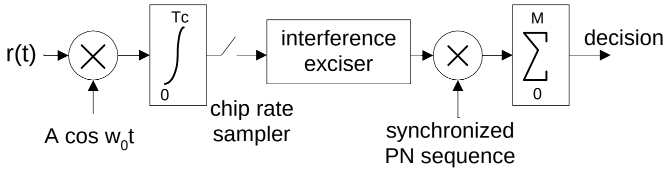
Figure captions:

Fig. 1 Block diagram of a DS/BPSK receiver with interference excision

Fig. 2 Decomposition process for a narrowband Gaussian interference with bandwidth 10% and center frequency 0.527π rad
Subcaptions:
a TSA exciser (two possible decompositions)
b UWPT exciser (highest level J=4)

Fig. 3 BER performance for a DS/BPSK system with UWPT and TSA excision
Subcaptions:
a Single tone interference
b Narrowband Gaussian interference with 10% bandwidth

Figure 1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Tc
0
chip rate
sampler
interference
exciser
synchronized
PN sequence
M
0
decision

Figure 2

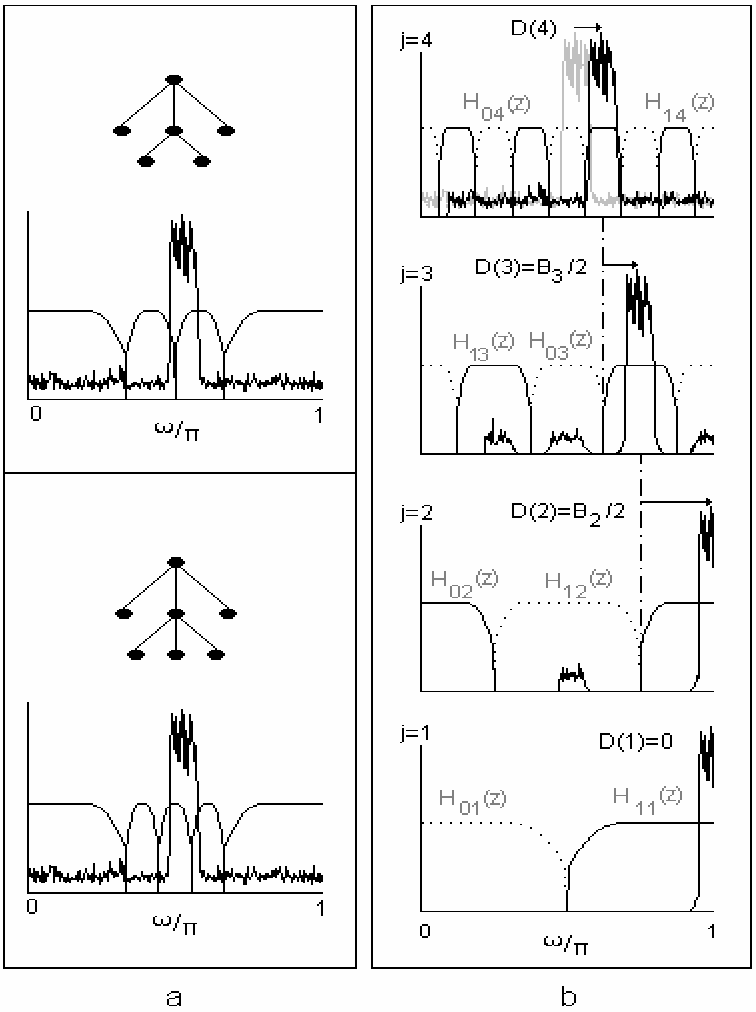
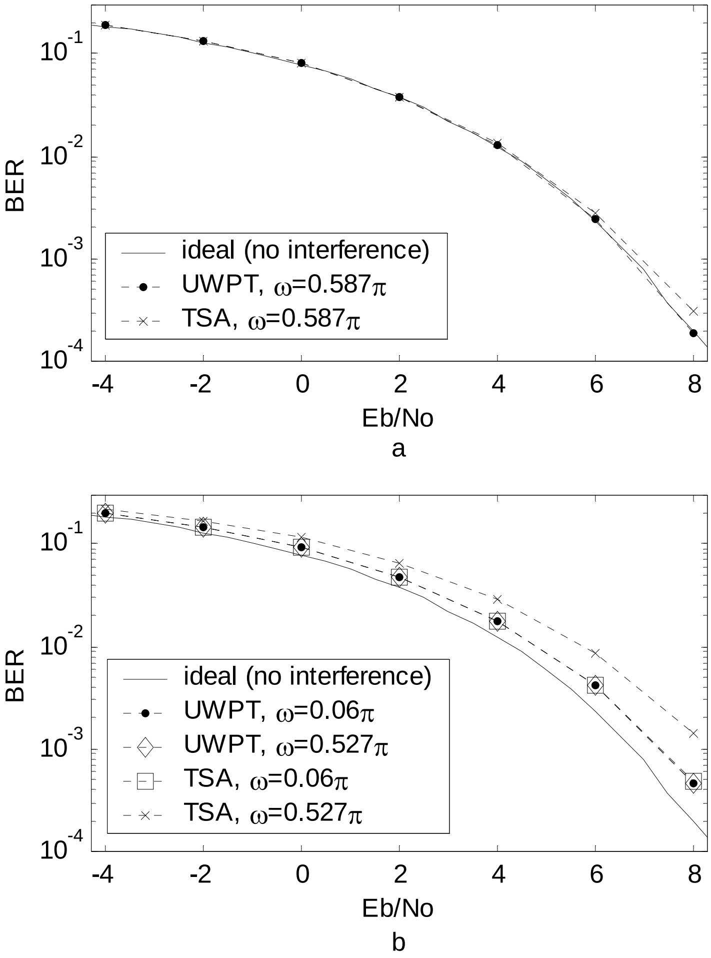

0
ω/π
1
0
ω/π
1
j=4
D(4)
H04(z)
H14(z)
j=3
D(3)=B3/2
H13(z)
H03(z)
j=2
D(2)=B2/2
H02(z)
H12(z)
j=1
D(1)=0
H01(z)
H11(z)
0
ω/π
1
a
b

Figure 3


BER
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10^-2
10^-3
10^-4
-4
-2
0
2
4
6
8
Eb/No
ideal (no interference)
UWPT, ω=0.587π
TSA, ω=0.587π
a
BER
10^-1
10^-2
10^-3
10^-4
-4
-2
0
2
4
6
8
Eb/No
ideal (no interference)
UWPT, ω=0.06π
UWPT, ω=0.527π
TSA, ω=0.06π
TSA, ω=0.527π
b