Interference excision algorithm for Frequency Hopping Spread Spectrum based on Undecimated Wavelet Packet Transform.

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Abstract: This paper presents an algorithm for reducing narrowband interference effects in Frequency-Hopping Spread-Spectrum (FH-SS). The method is based on the Undecimated Wavelet Packet Transform (UWPT), and it improves the performance obtained in previous methods. Some experimental results illustrate the suitability of the algorithm.

Introduction: Frequency Hopping Spread Spectrum is a digital modulation, which is robust against noise and interference, and generally used in non-coherent systems. Despite of this robustness, FH-SS systems can suffer from narrowband high energy interference [1]. Different techniques have been developed to eliminate interference in SS communications. These techniques are based on the comparison among signal and interferences, using adaptive filters and transform domain filtering [2].

This paper focuses on FH-SS systems with transform domain filtering, using wavelet transform (WT). WT analysis has special characteristics to confine and manage the signal spectrum in subbands. The algorithm discards the contaminated or jammed subbands at the synthesis stage. However, an interband spectral leakage that cannot be solved with fixed time-frequency resolutions can appear during this process. Thus, in this paper, irregular time-frequency decomposition by Wavelet Packet Transform (WPT) [3] is proposed. WPT allows selecting the subband tree structure filters [3]. This paper proposes a new algorithm based on the UWPT that uses frequency shifts to confine the narrowband interference within one transform subband.

FH-SS receiver with interference excision: The FH-SS receiver, illustrated in Fig. 1, is a standard FH-SS receiver with one additional block for interference excision. Input signal r(t) is demodulated in quadrature for all the FH-SS frequencies f_c, where $c\in[0,\ldots,m-1]$, and m is the total number of frequencies. Each demodulator output is low pass filtered, sampled and finally divided and processed in blocks by the excision filter. These blocks are: $X_{cr}+jX_{ci}$, $c\in[0, \ldots, m-1]$. After the excision filter, the signal is free from interferences and each symbol is detected with a non-coherent energy threshold. A similar scheme is proposed for DS-SS systems in [4].

The excision filter: The UWPT is a translation invariant and redundant transform, where no decimation is done after the analysis filtering [5]. Thus, analysis and synthesis filters are different at each level, since zeros need to be added in-between the filters' coefficients. At the "i" level, $2^{(i-1)}-1$

zeros are introduced in-between each pair of coefficients. As shown in Fig. 2, the UWPT at every resolution level divides the spectrum in two, due to its scaling property [6]. In this case, 16 coefficients Daubechies filters [6] have been used.

The algorithm implements an analysis process, running from the level with more frequency resolution (level "J"), to the one with less resolution (level "1"). At this first level "J", the input vector is the original signal from a pair of demodulators $X_J=(X_{Jr}+\mathrm{j}X_{Ji})$. The algorithm shifts the signal in the frequency domain, to center the interference in a subband. The filtering process is done for every frequency shift, d(J). The number of shifts is given by the bandwidth of the filters (B_J), $d(J)\in[0,..,B_J]$. Thus, the output vectors using a periodic extension of the input signal are:

$$W_{J,0,d(J)}(n)=\sum_{l=0}^{L-1}\mathrm{h}(l)(X_{J,d(J)}(n-2^{J-1}l)) \qquad (1)$$

$$W_{J,1,d(J)}(n)=\sum_{l=0}^{L-1}\mathrm{g}(l)(X_{J,d(J)}(n-2^{J-1}l)) \qquad (2)$$

where h(l) and g(l) are the filters, L is the length of the filters and $X_{J,d(J)}$ is the frequency shifted input vector. Once the decomposition at level "J" is done for every frequency shift, the energy difference between every pair: $W_{J,0,d(J)}$, $W_{J,1,d(J)}$ is calculated. The algorithm selects the pair with a greater energy difference, defined as:

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

where N is the number of elements in $W_{J,1,d(J)}$ and $W_{J,0,d(J)}$.

The frequency shift for this selected pair is the optimum, $D(J)=\{d(J)|\max(\Delta E_{J,d(J)})\}$, and the vector with greater energy from this pair ($W_{J,0,D(J)}$ or $W_{J,1,D(J)}$) contains the interference, thus it is chosen as the new input vector X_{J-1}, at the next resolution level "J-1". The other vector from the selected pair is saved together with D_J. If the energy difference is similar for all the pairs, the interference bandwidth is greater than the filters bandwidth at level "J", and they cannot concentrate the whole interference. Then, the algorithm must start at a lower resolution level, "J-1".

Once the filtering at level "J" is done due to the scaling property between filter responses as shown in Fig. 2, the frequency shift range for the following levels is bounded to two values, $d(J-1)=\{0,B_{J-1}/2\}$. Finally, when level "1" is met, the X_0 vector, which concentrates the interference, is removed. At this step, the synthesis 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: Simulations have been carried out using the FH-SS receiver scheme shown in Fig. 1 and Binary Frequency Shift Keying (BFSK) modulation with 5 orthogonal channels. The offset between frequencies in each BFSK channel is 1KHz and separation between channels is 2 KHz. Interference is a single continuous tone that changes its frequency and with a power 14 dB higher than the signal's. In addition to this, the interference includes additive white gaussian noise of 12 dB SNR. Results have been obtained from 10^8 transmitted bits.

Fig. 3 shows the probability of error (Pe) for three design alternatives: without any excision filter (traditional scheme), with an FFT and UWPT excision filter. The Pe is measured against the frequency offset between signal and interference, from 0 to the channel central frequency (F_c).

Results show the good performance of the system with proposed parameters. The maximum probability of error (Pe) is 0.0009 against the traditional scheme, with a minimum Pe of 0.08. Additionally, the Pe for the FFT excision filter is greater for all the frequencies. But the Pe difference between the two transforms is reduced for frequency offsets close to 0. This is due to the proximity of the interference to the signal, and both transforms in this case degrade the FH-SS signal

Conclusions: In this paper, an excision algorithm based on UWPT has been presented to remove narrow bandwidth interferences, in FH-SS systems. Results from one experiment are displayed, illustrating the performance of the algorithm. Other experiments with different parameters have been performed in order to confirm the validity of the algorithm for the general case.

The final conclusion is a robust interference avoidance algorithm suitable for FH-SS systems.

References

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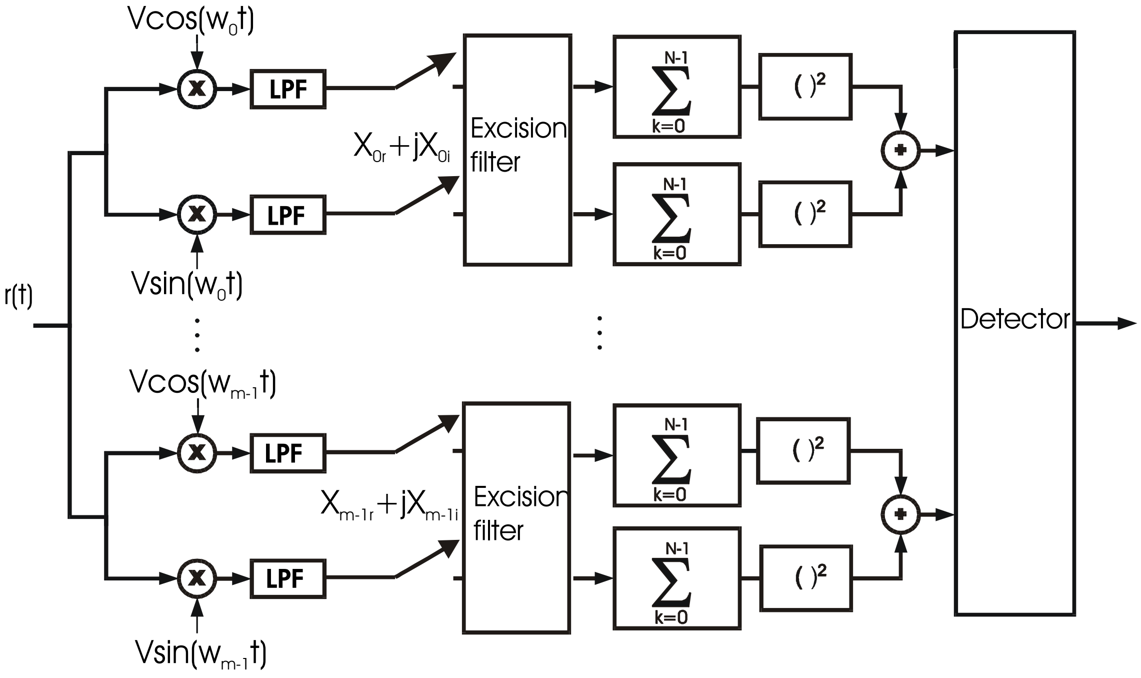
Figure captions:

Fig. 1 FH-SS receiver blocks: demodulator, low pass filter, excision filter, non-coherent integrator and detector

Fig. 2 Low (H) and High (G) frequency response filters, for UWPT using 16-Daubechies coefficients. Levels from 3 to 1

Fig. 3 Probability of error vs. interference frequency offset for three excision filter schemes: without excision filter, with FFT and with UWPT filter

Figure 1



Vcos(w0t)
LPF
LPF
Vsin(w0t)
X0r+jX0i
Excision filter
N-1
k=0
( )2
r(t)
Detector
Vcos(wm-1t)
LPF
LPF
Vsin(wm-1t)
Xm-1r+jXm-1i
Excision filter

Figure 2

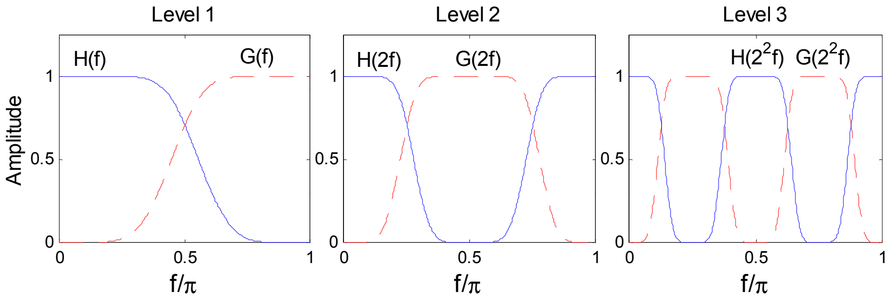
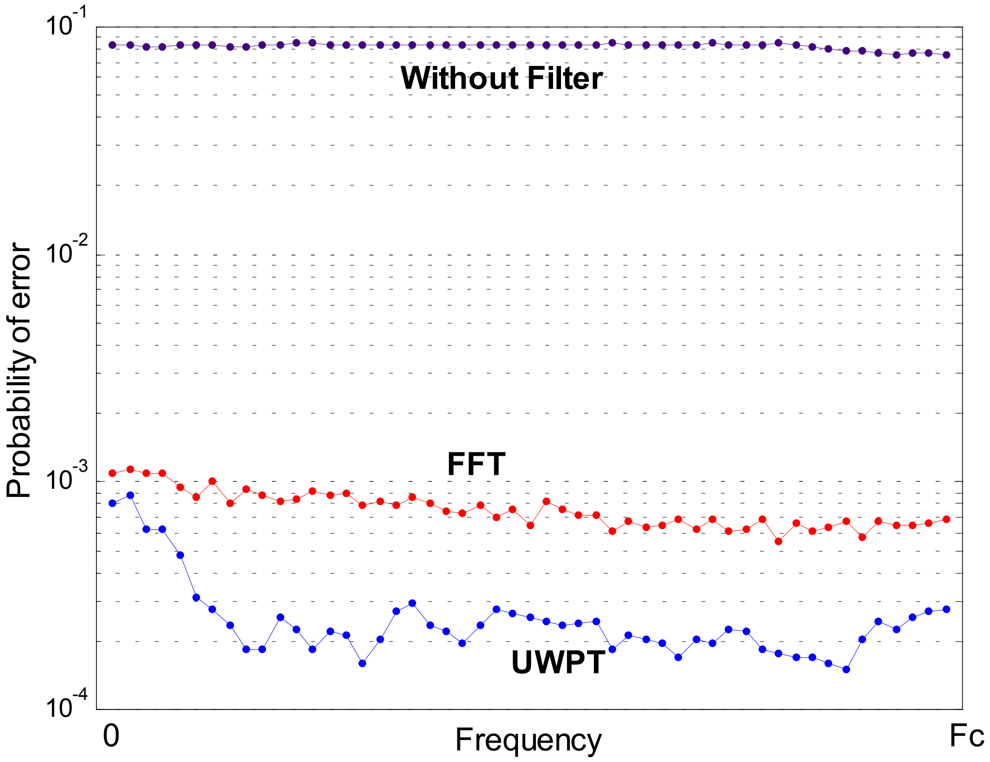

Level 1
Level 2
Level 3
H(f)
G(f)
H(2f)
G(2f)
H(2²f)
G(2²f)
Amplitude
1
0.5
0
0
0.5
1
f/π
f/π
f/π

Figure 3


10^-1
10^-2
10^-3
10^-4
Probability of error
Without Filter
FFT
UWPT
0
Frequency
Fc