A narrowband interference suppression method based on adaptive WPT

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Abstract. A narrowband interference (NBI) suppression method based on adaptive WPT is proposed. Firstly, the optimum parameters of the frequency shift and the highest resolution level are selected using Genetic algorithm. Then the adaptive wavelet packet decomposition based on parity checking is done to the shifted signal. Finally the interference-free signal is obtained by setting the sub-band with interference to zero and being reconstructed. Simulation results show that this algorithm can both suppress single tone and multi-tone interference effectively.

1. Introduction
The anti-jamming ability of a direct sequence spread spectrum (DSSS) system can be improved by interference suppression techniques. Wavelet packet transform can suppress NBI effectively for its partial time-frequency analysis\(^1\)\(^-\)\(^7\). In particular, the shifted undecimated wavelet packet transform algorithm\(^8\) yields superior performance. But it can’t suppress multi-tone interference for it can’t do WPT correctly when each has one interference both in the left and the right node. In this paper, a narrowband interference suppression method based on adaptive WPT is proposed, which can suppress not only single tone interference but also multi-tone interference. Firstly, the interferences are frequency shifted to the centres of each sub-bands at the optimum highest resolution level. Then the adaptive wavelet packet decomposition based on parity checking is done to the shifted signal and the sub-bands with interferences are setting to zero. Finally, the interference free signal is reconstructed using the saved vectors and frequency shift.

2. NBI Suppression Based on Frequency Shift WPT
The flow chart of the NBI suppression based on frequency shift WPT is shown in figure 1.

Suppose the received signal \(r(n)\) is a DS/BPSK with NBI and AGWN. The baseband complex signal \(R(n)\) is obtained by making quadrature down conversion of the received signal \(r(n)\).

\[
R(n) = \sqrt{P}d(nT_s)c(nT_s - \varepsilon\tau)\exp[-j\omega_p nT_s + \Delta\phi] + I(n) + N(n)
\]  

(1)
Where $P$ is the signal power, $d(nT_e)$ is the binary data bit stream, $c(nT_e)$ is the spread code sequence, $\varepsilon\tau$ is the time delay of $c(nT_e)$, $\omega_d$ is the Doppler frequency, $I(n)$ is the complex NBI, and $N(n)$ is the complex AWGN.

In figure 1, the baseband received signal $R(n)$ entered into the NBI suppression module.

(1) Frequency shifted WPT. The NBI suppression based on the frequency shift WPT starts decomposition from the highest level $J$. Firstly, the NBI is moved to the center of the sub-band of $J$-th level. Suppose $J$ is the highest resolution level, and $B_J$ is its bandwidth of sub-bands. The optimum frequency shift $S_J$ is obtained by shifting $K$ times.

The received baseband signal $R(n)$ is frequency shifted $B_J/K$ each time. Then the shifted signal is filtered with $H_{0,J}(z)$ and $H_{1,J}(z)$ to get $W_{0,S_J(n)}$ and $W_{1,S_J(n)}$. Finally the energy difference can be calculated:

$$\Delta E_{S_J(n)} = \left| W_{0,S_J(n)} \right|^2 - \left| W_{1,S_J(n)} \right|^2$$

(2) The optimum frequency shift can be obtained when $\Delta E_{S_J(n)}$ reaches its highest value.

$$S(J) = \left\{ \frac{S_k(J)}{\max(\Delta E_{S_k(J)}), k = 1, 2, \ldots, K} \right\}$$

(3) The frequency shifted signal is filtered by $H_{0,J}(z)$ and $H_{1,J}(z)$ to obtain $W_{0,J}$ and $W_{1,J}$. Comparing $W_{0,J}$ with $W_{1,J}$, the bigger one contains the interference. At the remaining level, the optimum frequency shift is 0 if the interference is in $W_{0,J}$ and $B_{J-1}/2$ if the interference is in $W_{1,J}$.

The WPT is decomposed from the highest resolution level to the lowest level until the interference remains centred at the lowest level. Restore each vectors and frequency shifts for the following reconstruction.

(2) NBI suppression. In order to remove the NBI, set the sub-band including NBI to zero.

(3) Wavelet packet reconstruction. Reconstruct the NBI-free signal using the restored vectors and frequency shift from resolution level ‘1’ to ‘J’. Finally, the reconstructed signal $\hat{R}_{S_J}(n)$ is frequency shifted to the original place.

$$\hat{R}(n) = \hat{R}_{S_J}(n) \cdot e^{-j2\pi S_J(n)}$$

Finally, $\hat{R}(n)$ is sent to the de-spread and demodulation module to get the demodulated binary sequence $\hat{d}(n)$. This method can suppress one interference such as single tone or AR interference effectively. But for multi-tone interference, it can’t suppress under certain condition. A NBI suppression method based on adaptive WPT is proposed in this paper.

3. The NBI Suppression Method Based on Adaptive WPT

In order to suppress the multi-tone interference, the NBI suppression based on adaptive WPT is proposed in this paper. The optimum selection of $J$ and $S(J)$ based on GA is analyzed in the following.

3.1 The Optimum Selection of $J$ and $S(J)$

GA is used to select the two optimum parameters: the highest resolution level $J$ and the frequency shift $S(J)$. The flow chart of GA is shown in figure 2.

In figure 2, the GA contains 6 elements: parameters encoding, initial population creation, fitness function design, genetic operation design, control parameters setting and algorithm end condition setting, where the genetic operation includes selection, crossover and mutation.

3.1.1 Parameters encoding. Multi-parameter concatenated encoding is used in this paper to select two optimum parameters. For the frequency shift encoding, the length of the frequency shift is $B_J$ and
$B_i / 2^J$ can meet the precision requirement. So binary encoding is used and the length of the binary code is 4. For the optimum highest resolution level $J$, it is a positive integer and the value can be neither too big nor too small. The value range of $J$ in this paper is $[5, 12]$. So $J$ can be binary encoded with the length of 3. Finally, the two encodings above can be concatenated to be the input parameter of GA.

![The flow chart of GA.](image)

3.1.2 Fitness function design. Simulation results show that the difference of the sub-band energy is steady, if the NBI is centered at the sub-band. It is shown in figure 3.

![The energy difference of the sub-band.](image)

In figure 3, when the NBI is centered during 5~10 frequency shift step, the energy difference of the sub-band is steady. But when the NBI is at the edge of the sub-band, the energy difference is waved during 11~20 frequency shift step. So the steady function of the sub-band energy difference is used to select the optimum $J$ and $S(J)$. The steady function of the sub-band energy change is calculated:

$$P_{S(J)} = |\Delta E_{S(J)_{-1}} - \Delta E_{S(J)}| + |\Delta E_{S(J)_{-1}} - \Delta E_{S(J)}|$$

(5)

When $P_{S(J)}$ is minimum, the NBI is centered at the sub-band, and $\Delta E_{S(J)}$ is steady, where the frequency shift is the optimum selected shift.

The steady function of the sub-band energy change is used as the objective function in this paper. When the value of the objective function is bigger, the sub-band energy change is less steady, the individual performance is poorer, and the selected opportunity is smaller.

The objective function is transformed into the fitness function.

$$Fit(f(t)) = -f(x)$$

(6)

3.1.3 Genetic operation design. It includes selection, crossover and mutation.

(1) Selection. The first step of selection is to calculate the fitness. The sort-based fitness assignment is
used to assign the individual selection probability. Population is assigned by objective value, and the fitness is depended on the individual order at the population. The linear sort-based individual fitness is:

\[
    \text{Fit}(\text{Pos}) = 2 - SP + \frac{2(SP-1)(\text{Pos}-1)}{N-1}
\]  

(7)

Where \( \text{Pos} \) is the individual order at the population, \( SP \) is the selection pressure, and \( N \) is the population size. So the individual selection probability is

\[
    p_i = \frac{1}{N} \left[ \eta^+ - (\eta^+)^i \frac{N-1}{N} \right]
\]  

(8)

Where \( i \) is the individual sort number, \( 1 \leq \eta^+ \leq 2, \eta^- = 2 - \eta^+ \). The selection probability of each individual \( p_i \) is calculated. Its cumulative probability is

\[
    q_i = \sum_{k=1}^{i} p_k, \quad i=1,2,\ldots,N
\]  

(9)

Then, \( N \) random numbers \( n \) between 0 and \( q_N \) is produced. The parent individual is selected by fitness using roulette wheel selection (RWS), as if \( q_{i-1} \leq n \leq q_i \), the \( i \)-th individual is selected. Repeat the process above \( N \) times. \( N \) copied individuals are obtained.

(2) Crossover. For the parameters are binary encoded, one-point crossover is used for the genic recombination. Crossover is processed to the two selected parent individuals according to the setting probability to produce the two offspring individuals.

(3) Mutation. For the binary encoded individual, mutation is to flip the gene value of some gene loci.

3.2 Adaptive WPT

The shifted interferences are centered at each sub-band by selecting the optimum parameters based on GA. But when the left and the right node each have one interference, it can’t confirm whether the node should be decomposed by the sub-band energy value. An adaptive WPT based on parity checking is proposed in this paper.

Firstly, the sub-bands are numbered from 1 to \( 2^J + 1 \). Suppose the sub-bands with NBI are \( I_1, I_2, \ldots, I_M \). According to the characteristics of the wavelet packet decomposition, the interference is at the low frequency sub-band if \( I_n \) is odd, and at the high frequency sub-band if \( I_n \) is even. The relationship between the NBI number at \( j-1 \) level and the NBI number at \( j \) level is

\[
    I'_n = \begin{cases} 
    I_n + 1 & \text{if } I_n \text{ is odd} \\
    \frac{I_n}{2} + 1 & \text{if } I_n \text{ is even}
    \end{cases} \quad (n = 1, 2, \ldots, M)
\]  

(10)

So the number of NBI at the child node can be obtained by the parity of \( I'_n \). The child node decomposed continually if the NBI number of the node is equal or greater than 1. Otherwise save the decomposition results for the following reconstruction.

4. Simulation and Analysis

The performance of the NBI suppression was simulated in this paper. Both the GA-based optimum frequency shift WPT algorithm (GA-WPT) and the WPT algorithm proposed by E. Pardo in [8] (EWP-T) were implemented in order to compare their performances.

Suppose in the DSSS/BPSK system, the spread code is gold sequence with length 1023 and bit rate 5.115Mcps, the signal-to-interference power ratio of \(-40\)dB, and the carrier to noise ratio of 52dBHz. Two types of narrowband interferences were considered: a single tone interference with frequency \( 0.1386 \pi \) and a multi-tone interference with the frequency \([-0.0352 \pi, 0.0294 \pi, 0.3177 \pi]\).
4.1 The Optimum Parameters Selection Simulation

The optimum selection results of $J$ and $S(J)$ using GA-WPT and EP-WPT were compared firstly. Where, the optimum selection of $J$ is obtained from the selection of GA-WPT. The spectrum amplitude in the following figures are all divided $2 \times 10^6$.

(1) Single tone interference. Figure 4 shows the selection results for single tone interference.

(a) GA-WPT

(b) EP-WPT

Figure 4. The signal spectrum with the shifted single tone interference.

In figure 4, the selection results of GA-WPT are $J=7$, $S(J) = 109.375$KHz, and EP-WPT are $J'=7$, $S'(J) = 27.344$KHz. The shifted single tone interferences are both centered at the sub-band.

(2) Multi-tone interference. Figure 5 shows the selection results for multi-tone interference.

(a) GA-WPT

(b) EP-WPT

Figure 5. The signal spectrum with the shifted multi-tone interference.

In figure 5, the selection results of GA-WPT are $J=6$, $S(J) = 7.0565$KHz, and EP-WPT are $J'=6$, $S'(J) = 98.438$KHz. The three shifted interferences are all centered at sub-band by GA-WPT, but they are all at the edge of the high frequency sub-band by EP-WPT in order to obtain the maximum change of the sub-band energy.

The simulation results indicate that GA-WPT can select the optimum $J$ and $S(J)$ adaptively to make sure that all the shifted interferences are centered at the sub-band. But EP-WPT can’t shift all the interferences to the center of each sub-band under the condition of multi-tone interference.

4.2 The Bit Error Rate Simulation

The bit error rate (BER) performances are simulated in the following. The carrier to noise ratio is 40~50dBHz, with the corresponding signal to noise ratio after de-spread of 0~10dB.

The BER performance for the case of single tone interference is shown in figure 6.
In figure 6, the GA-WPT BER curve is nearly the same with the EP-WPT results. The two algorithms can both suppress the single tone interference.

The BER performance for the case of multi-tone interference is shown in figure 7.

In figure 7, for the case of multi-tone interference, the signal can still be demodulated by GA-WPT. While it can’t be demodulated by EP-WPT, for EP-WPT can’t suppress the multi-tone interference. Comparing figure 6 with figure 7, the BER curve of multi-tone interference using GA-WPT is worse than single tone interference. That’s because the useful sub-bands removed increase as the sub-bands with multi-tone interference increase.

5. Conclusions
For the multi-tone interference can’t be suppressed by EP-WPT, a narrowband interference suppression method in DSSS system based on adaptive WPT is proposed in this paper. The optimum parameters of the frequency shift and the highest resolution level are selected by genetic algorithm, which can make sure that the interferences can all be shifted to the center of each sub-band, and the adaptive wavelet packet decomposition based on parity checking is done to the shifted signal. Thus, the interferences can be suppressed thoroughly. The simulation results show that the GA-WPT algorithm can suppress the interference effectively with the independence of the interference type.

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