Comparison of Narrowband Interference Suppression Methods for OFDM Systems

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***Abstract* – In this paper we compare two schemes for suppression of narrowband interference (NBI) in OFDM wideband systems. The first one is based on a frequency excision method and the second one is based on adaptive narrowband filtering for the detection and suppression of the interfering signal. The study shows that the two schemes give slightly different performance depending on the type of the channel. It could be seen that it is recommended both methods to be applied together in order to combat effectively the NBI and to obtain better performance for the wideband OFDM system.**

***Keywords* – Narrowband interference suppression, OFDM systems, Adaptive filtering.**

I. INTRODUCTION

Orthogonal Frequency Division Multiplexing (OFDM) is becoming leading technology for many applications, such as various kinds of broadband communication systems and recently for Ultra Wide-Band (UWB) systems [1]. Due to their relative low transmission power such systems are very sensitive to Narrowband Interferences (NBI). Because of the spectral leakage effect caused by DFT demodulation at the OFDM receiver, many subcarriers near the interference frequency will suffer serious SINR degradation, which could deteriorate and even block communications [2]. Similar is the case in cable communications systems over unshielded pairs with radio frequency interference, which usually could be treated as NBI for broadband OFDM system. Therefore, NBI suppression is of primary importance for such systems.

The issue of NBI suppression for wideband OFDM systems has been studied extensively in the last years and mainly two types of general approaches are proposed. The first one concerns various frequency excision methods, where the affected frequency bins of the OFDM symbol are excised or their usage avoided. The second approach is related to the so called cancellation techniques, aimed at elimination or mitigation of the effect of the NBI on the received OFDM signal. In most cases the degradation in a wideband OFDM based receiver is beyond the reach of the frequency excision method when the SIR is less than 0dB. Thus, mitigation techniques employing cancellation methods, one of which is based on adaptive notch filtering, are recommended as an alternative [3], [4],[5].

In this paper two schemes for suppression of NBI are compared. The first is a frequency excision method and the second is a cancellation method based on adaptive digital filtering using the LMS algorithm to adapt to the central frequency of the NBI [6]. The study shows that the two schemes give slightly different performance depending on the type of the channel. It could be seen that it is recommended both methods to be applied simultaneously in order to combat effectively the NBI, and to obtain better performance for the wideband OFDM system.

The paper is organized as follows. In section II and III the frequency excision method and the adaptive filtering scheme are considered. In section IV the simulation model used for the comparison is described. Section V presents the computer simulation results. Finally some conclusions are made.

II. FREQUENCY EXCISION METHOD

In the current scheme, a FFT based frequency-domain excision method is used to remove narrowband interferences [7]. The discrete Fourier transform output of each block of N_{FFT} samples, $r_{m,n}$ is given by:

$$r_{m,n} = \sum_{k=1}^{N_{FFT}} r_{m,k} e^{-j2\pi kn/N_{FFT}}, \quad k = 1,....N_{FFT} \qquad (1)$$

In the frequency domain, the narrowband interference manifests itself as a peak in the spectra. By comparing the magnitude of each frequency bin to a threshold and limiting those bins within the threshold, interferences can be excised. The effectiveness of the FFT based method depends on the selection of the threshold. The following method is used for the determination of the threshold. The mean value of the logarithm amplitude of the frequency bins and its variance are computed:

$$T_{mean} = \sum_{n=1}^{N_{FFT}} \frac{10 \log_{10} |r_{m,n}|}{N_{FFT}} \qquad (2)$$

$$T_{\mathrm{var}} = \frac{1}{N_{FFT}}\left[\sum_{n=1}^{N_{FFT}}\left(10\log_{10}|r_{m,n}|\right)^2 - \frac{1}{N_{FFT}}\left(\sum_{n=1}^{N_{FFT}}\left(10\log_{10}|r_{m,n}|\right)\right)^2\right] \qquad (3)$$

The threshold is determined according to the mean value and variance and is given by:

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$$T_{excision} = Tmean - \alpha T_{var}^{1/2} \tag{4}$$

The scale factor α in the above equation is adjusted to maintain the threshold at some value of the noise floor. Each frequency bin is compared to the threshold and if it exceeds the threshold, its value is held at the threshold. After IFFT, the signal is much less contaminated with narrow band interferences.

III. ADAPTIVE NARROWBAND FILTERING

Compared with the desired wideband signal the interference occupies a much narrower frequency band, but with a higher power spectral density. On the other hand the wideband signal usually has autocorrelation properties quite similar to that of AWGN, so filtering in the frequency domain could be realized. The filtering is performed at the input of the OFDM demodulator. To do this, a simple variable filter section with independent tuning of the central frequency and the bandwidth is used which is then turned into adaptive to implement it in an OFDM receiver. A realization based on second-order Gray-Markel lattice circuit is used [8] – Fig. 1. Using that circuit it becomes possible to implement a second-order notch/bandpass filter illustrated in Fig. 2.

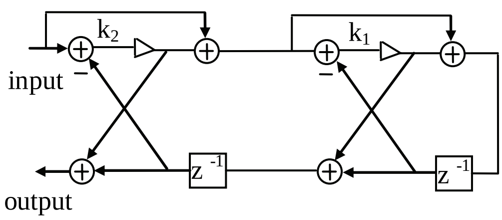

Fig. 1. Second-order lattice Gray-Markel circuit realizing all-pass function A(z)

This implementation has two very important advantages: first extremely low passband sensitivity that means resistance to quantization effects, second independent control of central frequency and filter bandwidth.

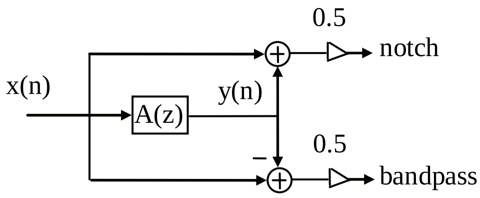

Fig. 2. Second-order notch/bandpass filter

Thus if the allpass function A(z) is

$$A(z) = \frac{k_2 + k_1(1+k_2)z^{-1} + z^{-2}}{1 + k_1(1+k_2)z^{-1} + k_2 z^{-2}} \tag{5}$$

then k_1 controls the central frequency ω_0 while k_2 is related to the bandwidth BW via

$$k_1 = -\cos\omega_0 \tag{6}$$

$$k_2 = \frac{1-\tan(BW/2)}{1+\tan(BW/2)}. \tag{7}$$

BW is directly connected to the distance from the pole to the unity-circle and transforming the structure in Fig.4 into an adaptive filter, it is possible to fix the bandwidth and implement an adaptive IIR filter free of stability problems. Adapting k_1 the central frequency can be shifted around the unity-circle.

For the adjustment of filter coefficient a Least Mean Squares (LMS) algorithm is applied as follows

$$k_1(n+1) = k_1(n) - \mu e(n)[x(n-1) - y(n-1)]; \tag{8}$$

where e(n) is the error signal and μ is the step size controlling the convergence speed.

In order to ensure the stability of the adaptive algorithm the range of the step size μ should be set according to [6]

$$0 < \mu < \frac{K}{L\sigma^2}. \tag{9}$$

In this case L is the filter order, σ^2 is the power of the signal [x(n-1) – y(n-1)] and K is a constant depending on the statistical characteristics of the input signal. In most of the practical situations K is approximately equal to 0.1.

IV. SIMULATION MODEL

To evaluate the performance of the NBI suppression methods simulations relative to baseband are conducted assuming standard OFDM receiver.

The information source is modeled by a generator of uniformly distributed random integers based on the modified version of Marsaglia's "Subtract with borrow algorithm" [9]. This classes of non-linear random number generators, called add-with-carry (AWC) and subtract-with-borrow (SWB), are capable of quickly generating very long-period pseudo-random number sequences using very little memory. These sequences are essentially equivalent to linear congruential sequences with very large prime moduli. So, the AWC/SWB generators can be viewed as efficient ways of implementing such large linear congruential generators. This method can generate all the double-precision values in the closed interval $[2^{-53}, 1-2^{-53}]$. Theoretically, it can generate over 2^{1492} values before repeating itself.

The channel encoder is implemented as a convolutional encoder. In the simulation, the code rate: Rc = 1/2 is chosen. In the receiver, a Viterbi hard threshold convolutional decoder is implemented.

A block interleaver - deinterleaver is implemented in the simulation which chooses a permutation table randomly using the initial state input that is provided.

The digital modulator is implemented as 256-point IFFT. The OFDM symbol consists of 128 data bins and 2 pilot tones. Each OFDM data can use different modulation formats. In the experiments Grey encoded 64-QAM modulation format is used. After the IFFT process, the prefix and suffix guard intervals are added.

The output signal s(t) in the transmitter is a complex OFDM symbol starting at time $t = t_s = kT_s$ [10]:

$$s_k(t) = \begin{cases} w(t - t_s) \sum_{i=-Ns/2}^{Ns/2-1} d_{i+Ns(k+1/2)} e^{j2\pi\left(fc - \frac{i+0.5}{Ts}\right)(t - ts - Tprefix)} \\ \quad , t_s \le t < t_s + T_s(1+\beta) \\ 0, \quad t < t_s \wedge t > t_s + T_s(1+\beta) \end{cases} \quad (10)$$

To minimize the spectrum leakage and limit the frequency bandwidth, windowing w(t) is applied to the individual OFDM symbols. A commonly used widow type is Raised Cosine Window, defined as:

$$w(t) = \begin{cases} 0.5 + 0.5\cos\left(\pi + \frac{t\pi}{\beta Ts}\right), & 0 \le t \le \beta Ts \\ 1, \quad \beta Ts \le t \le Ts \\ 0.5 + 0.5\cos\left((t - Ts)\pi + \frac{t\pi}{\beta Ts}\right), & Ts \le t \le (1+\beta)Ts \end{cases} \quad (11)$$

In the simulations a roll-off factor of 0.025, is used.

For the wireless channel a multi-ray model with direct and delayed (reflected) components is used. The delayed components are subject to fading, while the direct one is not. To preserve total signal energy, the direct and delayed signal components are scaled by the square roots of $K/(K + 1)$ and $1/(K + 1)$, respectively. The delay τ is the difference between the propagation time of the delayed component and that of the direct one. To simplify simulations, a complex baseband representation of the system is used [10], [11]. Moreover, to keep simulation memory and computational loads to a minimum, it is desirable to sample at two times modulation symbol rate. This requires delay τ to be a multiple **κ** of the symbol period T_s. With $\tau = kT_s$, the discrete equivalence of the wireless channel simulation model, can be written:

$$r_i = y_i + n_i \quad (12)$$

Where r_i is the complex baseband signal at the receiver side, s_i is the transmitted symbol, y_i is the fading sample and n_i is the complex noise sample.

The fading channel is represented by a FIR filter, where the subscript i indicates that the sample is taken at time $t = iT_s$ and with tap weights given by h_k

$$y(i) = \sum_{j=0}^{N-1} s(i - j)h(j) \quad (13)$$

and

$$h_n = \sum_k \operatorname{sinc}\left(\frac{\tau_k}{T} - n\right) g_k . \quad (14)$$

Here, N is the number of major paths, {τk} is the set of path delays, T is the input sample period, {gk} is the set of complex path gains, which are not correlated with each other. To generate a particular path gain gk, the model performs the following steps. First, white Gaussian noise is generated. Then the noise is passed through a filter whose transfer function corresponds to the Jakes Doppler spectrum and the output values are interpolated so that the sample period is consistent with that of the signal. The filter is adjusted accordingly to obtain the correct average path gain.

The excision method is applied to the OFDM signal with a NBI at the input of the demodulator. As mentioned in section II the signal is converted into the frequency domain by FFT and the noise peaks in the spectra of the signal are limited to the determined threshold. After this the signal is converted back in the time domain and applied to the input of the demodulator. It should be noted that for more precise frequency excision, FFT of higher order than the one in the demodulator is applied.

For the realization of the suppression method the adaptive notch filter is connected at the receiver's input. An adaptation algorithm tunes the filter in such a way that its central frequency and bandwidth match to the NBI signal spectrum. In the simulations, the central frequency of the notch filter is chosen in such a way that it is equal to the NBI central frequency, while its bandwidth is equal to 20% of the bandwidth between two adjacent OFDM sub-carriers.

In the OFDM demodulator the guard prefix and suffix intervals are removed and 256-point FFT is applied. The pilot tones are removed and respective channel equalization of the OFDM symbol is performed. Finally, corresponding 64-QAM demodulation is done.

V. EXPERIMENTAL RESULTS

Using this general simulation model different experiments are performed, estimating the bit error ratio (BER) as a function of the Signal to Interference Ratio (SIR). The NBI is modeled as a single tone the frequency of which is located in the middle between two adjacent OFDM sub-carriers. Three types of channels are considered: AWGN, Rayleigh and Rician. The Rayleigh and Rician channels are subject to strong fading and additionally background AWGN is applied, so that the signal to AWGN ratio at the input of the OFDM receiver is 20dB. In Fig. 3, a standard Gaussian channel is considered. The SIR is varied from -20 dB to 10 dB. It could be seen that for high NBI, where the SIR is less than 0 dB both suppression methods lead to a significant improvement in performance. The filtering scheme gives better performance than the frequency excision method. This could be explained with the NBI spectral leakage effect caused by DFT demodulation at the OFDM receiver, when many sub-carriers near the interference frequency suffer degradation. Thus filtering out the NBI before demodulation is better than frequency excision. Additional improvement is achieved by employing both methods together. In the case of Rayleigh and Rician types of channels Fig.4 and Fig.5 it could be seen that similar results are obtained. It should be noted that the filtering scheme leads to a degradation of the overall performance when SIR >0, which is due to the amplitude and phase distortion of the filter. The degradation could be reduced by the implementation of a higher-order notch filter or avoided by simply by switching off the filter when SIR>0.

Such a scheme is easily realizable as the amplitude of the NBI can be monitored at the bandpass output of the code.

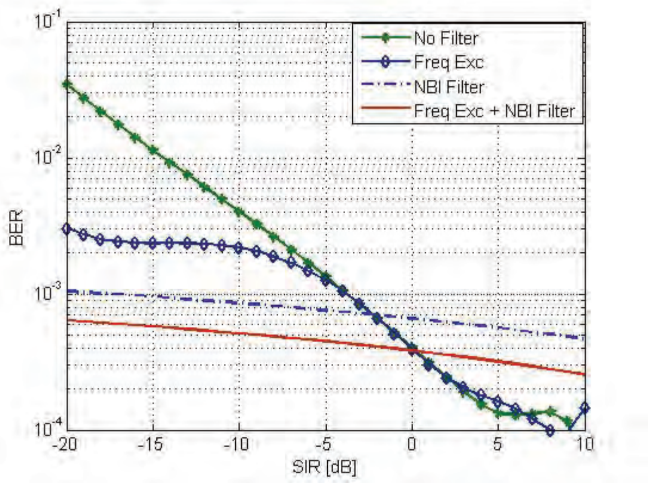

Fig. 3. BER as a function of SIR for AWGN channel

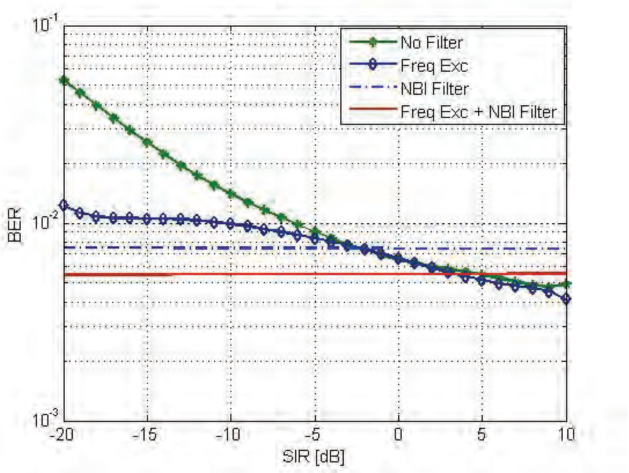

Fig. 4. BER as a function of SIR for Rayleigh channel

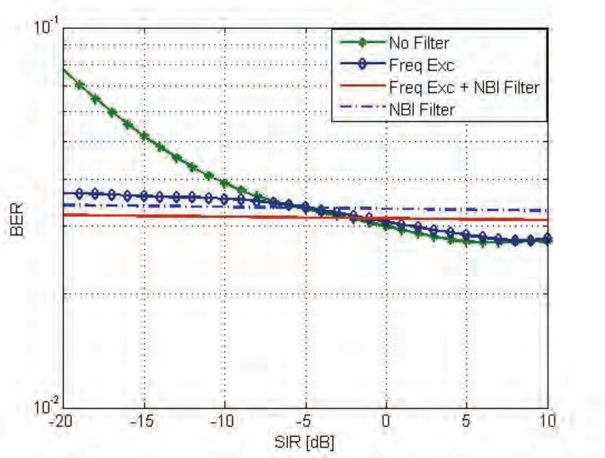

Fig. 5. BER as a function of SIR for Rician channel

VI. Conclusions

In this paper, a comparison of two schemes for suppression of NBI is performed. The first is a frequency excision method and the second is a cancellation method based on adaptive digital filtering using the LMS algorithm to adapt to the central frequency of the NBI. The experiments show that for high NBI, where the SIR is less than 0 dB both suppression methods lead to a significant improvement in performance. With SIR<0 the filtering scheme gives better performance than the frequency excision method. The performance of the two schemes is similar when using different types of channels. It could be seen that it is recommended both methods to be applied simultaneously in order to combat effectively the NBI, and to obtain better performance for the wideband OFDM system.

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