Mitigation of Impulse Noise in OFDM Systems

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Abstract

This paper proposes an adaptive thresholding technique to recover the Orthogonal Frequency Division Multiplexing (OFDM) signals corrupted by impulsive noise. In this technique, preliminary decisions are made to get the optimum threshold values for a novel decision directed impulse noise and based on the preliminary decisions in the transmitted data the noise component in each received input sample is estimated. When the estimated noise is above the given threshold, it indicates that impulse noise is present in the sample and the estimated noise component is subtracted from the input sample before final demodulation. In this paper the optimum threshold levels for varying impulse noise parameters are calculated.

Keywords: Orthogonal Frequency Division Multiplexing; Impulsive Noise; Adaptive Thresholding; Noise Estimation

1 Introduction

Impulsive noise is a common phenomenon occurring in channels which suffer from switching, manual interruptions, ignition noise, and lightning such as power line channels, Digital Subscriber Line (DSL) systems, and digital TV (DVB-T) [1-7]. Urban and indoor wireless channels as well as underwater acoustic channels also suffer from impulsive noise [8-10]. OFDM technology is used in many digital broadband communication systems. OFDM is more resistant to the effects of impulse noise compared to single carrier systems, because of the spreading effect of the Fast Fourier Transform (FFT). However impulse noise can still cause significant problems in OFDM systems. The theoretical effects of impulse noise in multicarrier systems have been analyzed [11], and a number of techniques for mitigating the effect of impulse noise have been described.

One approach is to identify peaks in the received time domain signal and reduce these by either clipping or nulling the sample [12-14]. This is effective only for impulse noise with peaks larger than the wanted OFDM signal. This will be true only in some extreme cases. In high signal to noise environments such as broadcast television, the impulse noise can be well above the background Gaussian noise, yet well below the OFDM signal. Several authors have used...
techniques that operate on the signal in the frequency domain [15-17]. The simulation results they present are for extreme cases with very large noise impulses. In [17], impulses are detected in the frequency domain by identifying subcarriers with extreme values. In this paper, preliminary decisions are made about the transmitted data and from these data, an estimate is made from the noise in the received signal. The estimated noise is subtracted from the original signal before final demodulation. When the input noise is impulsive, the technique substantially reduces the noise power. The technique depends on the fact that the signal appears random in the time domain and highly structured in the discrete frequency domain. The decision directed estimation technique requires a non linear noise estimation function. In this paper threshold type nonlinearities are investigated and the optimum thresholds found for varying impulse noise parameters.

The remainder of this paper is organized as follows. In Section 2, the proposed impulse noise mitigation model at the receiver is discussed. The Estimation algorithm for this method is described in Section 3. Section 4 presents the simulation results. Conclusions are drawn in Section 5.

2 Proposed Impulse Noise Mitigation Model

Fig. 1 shows the block diagram of a receiver with the new mitigation technique. The received OFDM baseband signal samples are given by,

\[ x(n) = s(n) + n_t(n) = s(n) + n_g(n) + n_i(n) \]  \hspace{1cm} (1)

where \( s(n) \) is the wanted OFDM signal, \( n_g(n) \) is the Gaussian noise and \( n_i(n) \) is the impulse noise. \( n_t(n) \) is the total noise at the input. The samples at the output of the non-linearity are serial-to-parallel converted to form the vector of \( N \) complex samples that are input to the \( N \)-point FFT.

The output of the FFT is the \( N \) point vector \( Y \). Preliminary decisions, \( d(k) \), about the transmitted data are made based on \( y(k) \). The noise component of \( y(k) \) is \( N_t(k) \). The observed noise \( N_p(k) \), is calculated using

\[ N_p(k) = y(k) - d(k) \]  \hspace{1cm} (2)

Except for extreme cases, most of the received subcarriers are correctly decoded and the observed noise is exactly equal to the received noise in that subcarrier. In the cases where the subcarrier is incorrectly decoded, ’decision noise’ will be added to the observed value. OFDM is more resistant to the effects of impulse noise than single carrier systems because of the spreading effect of the receiver FFT operation. The energy of each impulse is spread evenly across all of the subcarriers in that symbol. When there is more than one impulse in a received symbol period, \( T \), the contributions combine linearly in each subcarrier. When there are enough impulses during
for the central limit theorem to apply, \( N_p(k) \) has a Gaussian distribution. The vector \( N_p \) is then converted back into the discrete time domain using an inverse FFT to give the vector \( n_p \). If there are no decision errors, \( n_p(n) = n_t(n) \). However even in the presence of decision errors \( n_p(n) \) contains some information about \( n_t(n) \). Then \( n_p(n) \) is the input to an estimation device to generate an estimate \( \hat{n}_t(n) \) of the total input noise. This is subtracted from \( x(n) \) to generate \( s(n) \). The rest of the receiver is a standard OFDM receiver consisting of FFT etc.

3 Estimation Algorithm

The task of the estimation algorithm is to estimate the presence and size of noise impulses. A number of algorithms are possible. In this paper, two estimation algorithms are considered: a threshold operating on the real and imaginary components separately and an estimation algorithm operating on the amplitude of each sample. If the estimated noise component in a sample is above the threshold, then the estimated value is subtracted from the input signal before the second stage of demodulation, if it is below the threshold the input sample is unchanged. The operation of the amplitude non-linearity is described by:

\[
\hat{n}_t(n) = \begin{cases} 
  a n_p(n) & \text{for } |n_p(n)| > \alpha \\
  0 & \text{for } |n_p(n)| > \alpha
\end{cases}
\]  

To describe the second non-linearity, represent \( \Re(n_p(n)) \) as \( r_p \), \( \Re(n_t(n)) \) as \( r_t \) and \( \Re(n_d(n)) \) as \( r_d \). Then the operation of the real non-linearity is described by

\[
\hat{r}_t = \begin{cases} 
  \alpha r_p & \text{for } |r_p| > \alpha \\
  0 & \text{for } |r_p| < \alpha
\end{cases}
\]  

The operation of the imaginary non-linearity is identical. For the technique to be effective in reducing the overall Bit Error Rate (BER) of the system, \( n_t(n) \) must be impulsive (not stationary Gaussian) and the estimation algorithm must be non-linear. If the estimation process is linear, it will appear to improve the received constellation as each point moves towards the value \( d(k) \), but the points will move closer to both incorrect and correct decision points. However, the technique is very effective if non-linear processing is used and the noise is impulsive. This depends on the fact that for large values of \( n_t(n), n_p(n) \approx n_t(n) \).

A number of models for impulse noise have been presented in the literature [4], [5], [10], [18]. Some characterize only the probability density function of the amplitude of the noise, whereas others also consider the time correlation of impulse events. In the case of gated Gaussian noise, the noise is the sum of Additive White Gaussian Noise (AWGN) of variance \( \sigma_n^2 \) and a second higher variance Gaussian noise component which lasts for a fraction, \( \mu \) of the time duration of each OFDM symbol and which has variance \( \sigma_i^2 \) during this time. (i.e. the variance is calculated over only \( \mu T \) not over \( T \)). In general \( \sigma_i^2 \gg \sigma_n^2 \), then the total noise power is \( \sigma^2 = \mu \sigma_i^2 + \sigma_n^2 \). Each of these variances is for the real and imaginary components taken separately. The impulsive samples are spread randomly throughout each OFDM symbol. The gated Gaussian model is used because it gives a good indication of the performance of OFDM systems. It also allows the length and power of the impulse noise to be varied in a way that makes clear the practical implications of the technique.
4 Simulation Results

Simulations were used to examine how the performance of decision directed noise mitigation technique depends on the non-linear estimation process. The performance is measured both in terms of Symbol Error Rate (SER) and the normalized mean square error of the noise estimation. The normalized error is given by:

\[ E\left\{ |\hat{n}_t - n_t|^2 \right\} / E\left\{ |n_t|^2 \right\} \]

The simulations are for a flat fading channel. For each simulation, the average power in each of the real and imaginary components of the wanted OFDM signal is unity. 64QAM modulation and 2048 subcarriers were used. In the simulations it was assumed that all subcarriers were carrying data and no pilot tones were used. The thresholds are standardized in terms of the standard deviation of the wanted OFDM signal.

Fig. 2 shows the results for amplitude thresholding, while Fig. 3 shows the results for real
and imaginary thresholding. The weighting factor was set as $a = 1$. It is clear that for these parameters, the use of an amplitude threshold gives better performance than a real and imaginary threshold. Amplitude thresholding gives better results because in the gated Gaussian model, both the real and imaginary components of a given sample are either impulsive or non-impulsive.

Figs. 3 and 4 shows the resulting SER as a function of $E_b / N_o$, where $N_o$ is the single sided spectral density of the white Gaussian. The impulse noise parameters are $\sigma_i^2 = 0$ dB and $\mu = 0.01$. In other words, for each plot, the impulse noise is kept constant and the effect of varying $E_b / N_o$ is measured.

Fig. 4 shows how the normalized mean square error in the noise estimation process varies with threshold. A comparison of Figs. 2 and 4 indicates that the threshold which gives the Minimum Mean Square Error (MMSE) (0.4) is not the same as the threshold which gives the minimum SER (0.5). This is also true for other parameters and is because the time domain noise is partially correlated. Fig. 5 explores this relationship.

Fig. 4: Normalized mean square error verses amplitude threshold $\alpha$, and varying $E_b / N_o$ for $\sigma_i^2 = 0$ dB and $\mu = 0.01$

Fig. 5: SER verses normalized mean square error and varying amplitude threshold $\alpha$, for $\sigma_i^2 = 0$ dB and $\mu = 0.01$
Fig. 6 shows the normalized mean square error as a function of threshold for $\sigma_i^2 = -12$ dB and $\mu = 0.16$. In other words the impulsive noise is for a longer proportion of the symbol period but at a lower level. For these values the impulse mitigation is still effective but the selection of the threshold level is much more critical in this case. This is because the impulsive noise is only slightly above the background of white Gaussian noise and the ‘decision noise’.

![Normalized mean square error versus amplitude threshold](image)

Fig. 6: Normalized mean square error verses amplitude threshold $\alpha$, and varying $E_b / N_o$ for $\sigma_i^2 = -12$ dB and $\mu = 0.16$

## 5 Conclusions

Simulation results show that the proposed technique analysis the effect of using different non-linear estimation algorithms in decision directed impulse mitigation for OFDM. It is shown that better performance is obtained using thresholds based on the amplitude of the complex baseband signal rather than nonlinearities which operate on the real and imaginary components separately. For a given impulse noise parameters, the optimum threshold varies only slightly with the level of background white noise. The impulse noise mitigation gives the greatest improvement in performance when the impulsive noise energy is concentrated in a small proportion of a symbol period. For a given total impulse noise energy, the choice of threshold becomes more critical if the energy is spread over more signal samples.

## References


