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Adaptive fuzzy assisted detector under impulsive noise for DVB-T systems

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ABSTRACT

The main novel contribution of this paper is the improvement achieved on the Digital Video Broadcasting-Terrestrial (DVB-T) system by the addition of a fuzzy median filter to reduce the effect of impulsive components. The proposed detector includes the fuzzy median filter and can be adaptively adjusted according to the noise level and type of the noise. The system is studied under Gaussian and impulsive noise. Simulation results show that fuzzy assisted detector reduces the effect of impulsive noise and improves the performance of the system significantly while also working efficiently in Gaussian noise.

1. Introduction

Digital Video Broadcasting (DVB) turns to be a suite of internationally accepted open standards for digital television after switching from the analogue to digital television broadcasting. The first generation terrestrial DVB (DVB-T) standard that is based on Orthogonal Frequency Division Multiplexing (OFDM) introduced an advance in digital TV transmission with well-structured transmission. A large number of countries, including many European Union countries, has already deployed or planning to deploy DVB-T. Low-complexity and low-cost receiver design has been the main focus in order to enhance its popularity and enables its spreading around the globe [1]. High frequency efficiency of OFDM also played an important role in its adaptation and proposed it as the next generation communication and broadcasting standard. As the number of constellations in a DVB-T system increased, the data rate of OFDM systems could be increased significantly. However, in such OFDM systems as DVB-T, impulsive noise has been observed to effect system performance significantly [2,3]. Methods such as time domain processing before FFT transformation [4], OFDM with silent subcarriers and Reed–Solomon (RS) coding [5] have been successfully applied. Traditional methods of multicarrier signal detection in impulsive noise environments are using signal processing in time domain before demodulating the OFDM signals. Suppressing the effects of impulsive noise using these traditional methods in OFDM systems have been shown to provide a degree of protection, which is far away from theoretical bounds [4]. The RS coder in a complex field encodes the OFDM signal in such a way that, zero sub-carriers are placed in predefined consecutive positions, exploiting some properties of the OFDM signal. This method has been employed for impulsive noise suppression in [5]. However, it has been concluded that conventional error correction decoders cannot eliminate the effects of impulsive interference and Gaussian noise simultaneously. More effective iterative methods based on frequency-domain equalization in conjunction with impulsive noise estimation have been proposed by other researchers in order to combat impairments due to impulsive noise [6,7]. Other methdos such as time-domain approach with a pre-processing mean filter and RS coding [8] and compensation method suitable for DVB-T systems in the frequency-domain after OFDM demodulation [9] have been also proposed for the suppression of impulsive noise. In [10], a fuzzy assisted decorrelating detector has been proposed that uses a fuzzy median filter to eliminate the effect of impulsive noise in multipath CDMA systems so that detector also works efficiently in impulsive channels. In this paper, an adaptive detector is proposed based on the principle of fuzzy logic that is used to reduce the effect of impulsive components of noise to improve the DVB-T system performance. An optimal threshold value for the fuzzy median filter is searched for each value of Signal-to-Noise Ratio (SNR) and used to adjust to minimize Bit Error Rate (BER). Although the proposed detector improves the performance under the impulsive noise, it performs worse in Gaussian noise since the fuzzy median filter designed for impulsive noise also removes useful signal content along with noise. To solve this problem, the detector is modified

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to apply the fuzzy median filter only in the presence of impulsive noise so that the proposed detector is equally suitable for Gaussian noise.

The rest of the paper is organized as follows. Section 2 presents a short overview of the DVB-T system model. In Section 3, we discuss the addition of the fuzzy media filter to the DVB-T system. Section 4 presents the simulation results and their discussions. Finally, in Section 5 we conclude with a final overview of the obtained results.

2. System model

DVB-T employs OFDM as the transmission scheme. After performing RS coding, outer interleaving, inner coding (i.e. punctured convolutional code), and inner interleaving, inverse FFT is performed on the modulated data symbols before transmission. The data symbols are then transmitted block by block at a fixed rate after inserting the cyclic prefixes as Guard Intervals (GI) between two consecutive blocks [1]. After GI is removed, the received baseband DVB-T signal plus the impulsive noise, $v(k)$, can be expressed as

$$r_g(k) = \frac{1}{\sqrt{N_{\mathrm{FFT}}}} \sum_{n=0}^{N_u-1} X(n) \exp\left(\frac{2j\pi kn}{N_{\mathrm{FFT}}}\right) + v(k) \tag{1}$$

where $k = 1 \ldots N_{\mathrm{FFT}}$, N_{FFT} is the FFT length and $\{X(n)\}$ are the modulated data symbols of N_u subcarriers. In this paper, two-term Gaussian-mixture model, which is widely used, is adopted for the ambient noise. This noise model can be defined by the following probability density function:

$$f = (1-\varepsilon)v\left(0, \sigma^2\right) + \varepsilon v\left(0, \kappa\sigma^2\right) \tag{2}$$

with $0 \le \varepsilon \le 1$ and $\kappa \ge 1$. Here, ε and κ represent the probability that impulses occur and the variance factor of the impulsive component, respectively. The nominal Gaussian background noise with variance σ^2 is represented by the term $v\left(0, \sigma^2\right)$. The impulsive noise component is modeled with a larger variance, $\kappa\sigma^2$, Gaussian density as $v\left(0, \kappa\sigma^2\right)$. The Gaussian-mixture model (2) which is an approximation to the more fundamental Middleton Class-A noise model [11] has been extensively used to model impulsive noise arising in mobile radio channels.

3. Proposed adaptive fuzzy assisted detector

The effect of the impulsive noise should be suppressed at the DVB-T receiver by reducing the effects of extreme amplitudes. Hence, an adaptive filter that is based on fuzzy logic and rank ordering is added to the receiver as shown in Fig. 1. The received signal vector $\mathbf{r}_g = \left[r_g(1) \;\; r_g(2)\ldots r_g\left(N_{\mathrm{FFT}}\right)\right]$ is fed into the fuzzifier to calculate membership degrees by using the following Gaussian membership functions:

$$F(k) = \exp\left(\frac{-\left|\left|r_g(k)\right| - \mu_g\right|^2}{\left(2v_x\sigma_g\right)}\right) \tag{3}$$

where v_x is the constant that is used to adaptively set the range of fuzzifier applied, μ_g and σ_g are the median and standard deviation of the absolute value of the rank-ordered version of the received vector, $\mathbf{r}_g$, respectively. The filter is then applied to the element-wise multiplication of received vector. The elements of received signal vector after the application of fuzzy filter can be expressed as:

$$r_F(k) = r_g(k) \circ F(k) \tag{4}$$

where $\circ$ is the element-wise multiplication operator.

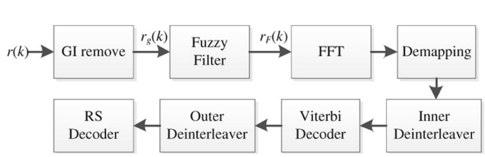

Fig. 1. Block diagram of the DVB-T receiver.

4. Simulation results

Extended simulation results are conducted to present the performance of adaptive fuzzy assisted detector for the DVB-T system both in Gaussian and impulsive channels. The key parameters of the simulated DVB-T system are given in Table 1. The other DVB-T parameters are used as defined in [1]. The first simulations are performed to investigate the effect of v_x in (3) on the performance of fuzzy assisted DVB-T system and determine an optimal value of this parameter. BER results are presented in Fig. 2 at different SNR values for the impulsive channel. It is observed from the results that the optimum value of v_x is between 0.02 and 0.06 for the given SNR range. The optimal choices of v_x values minimizing the BER at the given SNR values are presented in Table 2 together with the minimum BER values achieved. It is also concluded from the results of Fig. 2 and Table 2 that there is a linear relation between the optimal v_x and SNR as $v_x = 0.005\,\mathrm{SNR} + 0.03$. Hence, the fuzzy filter is adaptively set to v_x according to this linear relation. In Fig. 3, the fuzzy filter is applied to the DVB-T system at different SNR values for Gaussian channel ($\varepsilon = 0$). The results show that fuzzy assisted

Table 1
Simulation parameters.

Parameters	Specification
N_{FFT} (DVB-T mode)	2048 (2 K)
Number of active subcarriers	1705
GI fraction	1/4
Outer coding	RS (204, 188, t = 8)
Inner coding	Convolutional code with code rate 3/4
Signal constellation	QPSK

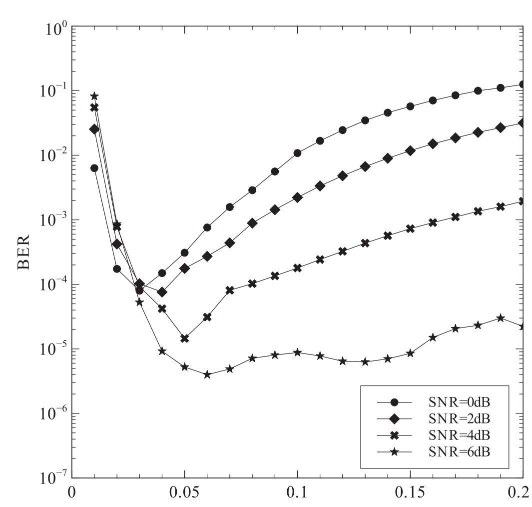

Fig. 2. BER against v_x under impulsive channel (ε = 0.2, κ = 100).

Table 2
Optimum v_x values at different SNR.

SNR	0 dB	2 dB	4 dB	6 dB
Optimum v_x	0.03	0.04	0.05	0.06
Minimum BER	7.99×10^{-5}	7.59×10^{-5}	1.45×10^{-5}	3.99×10^{-6}