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IMPULSE NOISE ESTIMATION IN FREQUENCY SELECTIVE FADING CHANNEL

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ABSTRACT

OFDM Orthogonal Frequency Division Multiplexing is a multicarrier modulation scheme. It is widely used in wired and wireless communication systems. Impulse noise can be mitigated by considering it as a sparse signal in time, and using recently developed algorithms for sparse signal reconstruction. We propose an algorithm that utilizes the guard band null subcarriers for the impulse noise estimation and cancellation.

Keywords: impulse noise, OFDM, discrete multitone, sparse signal reconstruction, estimation, compressive sensing.

1. INTRODUCTION

OFDM Orthogonal Frequency Division Multiplexing is also known as Discrete Multi-Tone (DMT).It is a Modulation techniques widely used in both wired and wireless system such as DSL, PLC and WIMAX respectively. OFDM is ideally suited to deal with frequency selective fading channel, and its performance may be dramatically impacted by the presence of impulse noise and AWGN .In fact, very strong impulse in time domain might result in the erasure of whole OFDM blocks of symbols at the receiver. While OFDM is ideally suited to handle ISI by frequency domain transmission and equalization using the Inverse Discrete Fourier Transform (IDFT)/Discrete Fourier Transform and cyclic prefix approach and the effect of AWGN is eliminated using a coded modulation techniques. In this work we focus on a scheme for impulse noise estimation and cancellation at the receiver. There are different statistical models present in literature survey. The three widely used models are the Gaussian mixture, the Middleton's Class A, and the symmetric alpha stable models. In this paper, we model impulse noise as a Gaussian process. This is based on the estimation of smart receiver method, which is implemented in the receiver side of the OFDM system to mitigate the impulse noise and AWGN in the frequency domain of the channel.

a) Impulse noise types, models and approaches for its removal

Impulse noise can broadly be divided into two types; Aperiodic impulse noise and periodic impulse noise. Aperiodic Impulse noise occurs in the range of 50 dB above the background noise level. In contrast, periodic impulse noise consists of impulses of longer duration and occurring periodically in time. In this paper, we focus on aperiodic impulse noise. The periodic impulse noise or block-sparse impulse noise can be converted into the model treated in this paper by using time domain interleaving. This technique is referred to as TDI-OFDM.

b) Our approach: utilizing null carriers for impulse noise detection and cancelation

In this process we used unused/null frequencies in order to obtain a signal-free subspace using this the impulse noise can be projected. The impulse noise is sparse in the time domain, we can estimate the locations of the impulses and their amplitudes and eventually subtract these estimates from the received signal. Estimation is obtained with a new low complexity scheme, by exploiting the structure of the projection matrix which is known as sub matrix of a unitary DFT matrix is extracting a block of adjacent subcarriers. The probability distribution of the impulse noise, which is assumed to be Bernoulli Gaussian with known parameters.

2. TRANSMISSION MODEL

The discrete-time complex baseband equivalent channel model for the OFDM signal has the function H is the Channel Induced by Cyclic Prefix Precoding, X is the Data added to the Channel, where Z is the additive white Gaussians noise. Time domain signal is related to the frequency domain signal by the circulant convolution matrix H is decomposed.

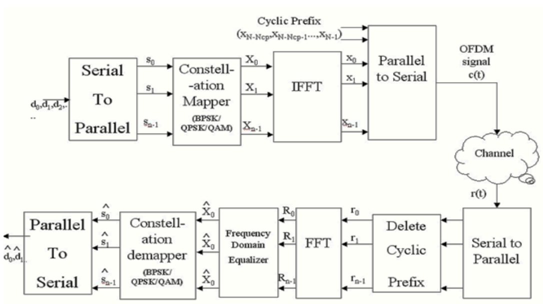

Figure-1. Basic OFDM system.

symbols in the block, after DFT demodulation. The equation of OFDM signal is follows in the derivation.

$$Y = HX + e + Z \tag{1}$$

Time domain signal is related to the frequency domain

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signal by,

$$x = F\hat{H}x \quad (2)$$

The circulate convolution matrix H can be decomposed as H = FHDF, where D = diag(˘ h) and h = √nFh is the DFT of the channel impulse response. Demodulation amounts to computing the DFT,

$$y = Fy = \hat{D}x + \hat{e} + Fe \quad (3)$$

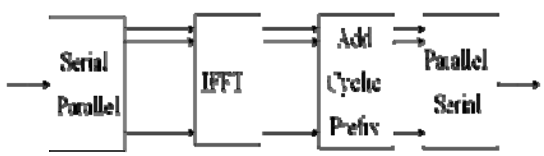

Figure-2. Basic OFDM Transmitter.

The probability that the OFDM block let us consider the case of p = 10−4, n = 1000, I0 = 40dB, N0 =0dB, and Ex = 20dB. One impulse is equal to 0.0952. Thus about 10% of the time, a block of n OFDM frequency domain symbols is corrupted by, one or more impulses. AWGN coded-modulation scheme is designed for the nominal SNR of 20 dB. Actually OFDM block is corrupted by at least one impulse is equal to 0.0952. Thus about 10% of the time, a block OFDM frequency domain symbols is corrupted by one or more impulses and the nominal SNR of 20 dB.

3. PROBLEM FORMULATION

In, OFDM frequency domain channel model. We use the sparse nature of e to estimate it and then remove it from the received signal. We use the subcarriers free of modulation symbols to estimate e. Here, subcarrier used for data transmission in the OFDM system. The remaining subcarriers are either not used, or used for transmitting known pilot symbols in the frequency domain, which are not shown here since we do not deal with channel estimation.

$$x = FHS\hat{x}\, d \quad (4)$$

where˘ d is frequency domain data symbol vector of dimension k ≤ n and where Sx is an n × k “selection matrix” containing only one element equal to 1 per column, and with m = n−k zero rows. The positions of the single 1s in the columns of Sx indicate the subcarrier used for data transmission in the OFDM system. x = FHSx˘ d, where˘ d is frequency domain data symbol vector of dimension k ≤ n and where Sx is an n × k “selection matrix” containing only one element equal to 1 per column, and with m = n−k zero rows. The positions of the single 1s in the columns of Sx indicate the subcarrier used for data transmission in the OFDM system.

$$y = F(e-\hat{e}) + \hat{z} \quad (5)$$

the variance per component of the corresponding frequency domain Gaussian plus impulse noise vector, Fe $+\hat{z}$.

4. OPTIMAL IMPULSE NOISE ESTIMATION

The MMSE estimate of e is given by the equation,

$$\hat{e} \triangleq \mathbb{E}[e|y'] = \sum_I p(I|y')\mathbb{E}[e|y', I] \quad (6)$$

A. Calculating

$$\mathbb{E}[e|y', I]$$

$$\hat{e}_I = \mathbb{E}[e_I|y', I] \triangleq \frac{I_0}{N_0}\Psi_I^H \Sigma_{\Psi_I}^{-1} y' \quad (7)$$

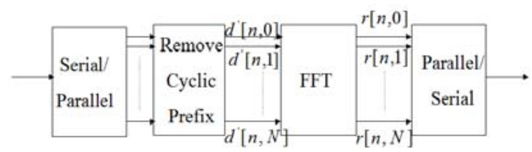

Figure-3. Basic OFDM Receiver.

The conditional MMSE estimator coincides with the linear MMSE estimator, given by,

$$\Sigma_{\Psi_I} \triangleq \frac{1}{N_0}\mathbb{E}[y'(y')^H|I] = I + \frac{I_0}{N_0}\Psi_I\Psi_I^H \quad (8)$$

SI denote the selection matrix of dimension n× |I| such that each column i is the position of the i-th component of the support I, we have,

$$\mathbb{E}[e_I|y', I] = S_I\hat{e}_I = \frac{I_0}{N_0}S_I\Psi_I^H\Sigma_{\Psi_I}^{-1}y' \quad (9)$$

B. Calculating p(I|y')

Using Bayes’ rule, we can write

$$p(I|y') = \frac{p(y'|I)p(I)}{p(y')} = \frac{p(y'|I)p(I)}{\sum_{I'} p(y'|I')p(I')} \quad (10)$$

Gaussian given I, therefore

$$p(I|y') = \frac{\exp(-\frac{1}{N_0}y'^H\Sigma_{\Psi_I}^{-1}y')}{\det(\Sigma_{\Psi_I})} \quad (11)$$

This is the constant multiplicative factor. The denominator denotes the, summation over all the computationally prohibitive.

C. Estimation of the support I

A sparse signal is identify by rank-deficient projection and it occur in additive noise is the middle problem in the CS literature.

1) CS based on convex relaxation

Three alternatives widely proposed in the literature to implement sparse signal estimation in the presence of noise are reviewed in the following.

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a) Candes-Romberg-Tao SOCP estimator

The Second-Order Cone Programming (SOCP) problem proposed,

$$\min \|\tilde{e}\|_1 \, \text{s.t.} \, \|y' - \Psi\tilde{e}\|_2 \leq \epsilon \tag{12}$$

b) Dantzig selector

An LP estimator is proposed for real vectors which is as follows,

$$\min \|\tilde{e}\|_1 \, \text{s.t.} \, \|y' - \Psi\tilde{e}\|_\infty \leq \lambda \tag{13}$$

c) LASSO

The convex relaxation method is known as LASSO

$$\min \frac{1}{2}\|y' - \Psi\tilde{e}\|_2^2 + \gamma\|\tilde{e}\|_1 \tag{14}$$

2) BCH-type Error Correction over the Reals

In the coding theory, the main problem is to solve the "locator polynomial" which is to find the location of the errors

3) Fast bayesian matching pursuit (FBMP)

A fast Bayesian recursive algorithm, MMSE estimate of the sparse signal jointly, based on the Bernoulli-Gaussian priors.

5. FINDING DOMINANT SUPPORT USING STRUCTURE

The semi-orthogonal structure of Ψ has follows two observations. First, locate the impulse noise location by

(i) project y on Fm

(ii) second observation is to find the semi-orthogonal structure.

This makes to calculate the MMSE estimate in a divide and-conquer manner, based on set of clustering.

$$|\psi_j^H \psi_{j'}| = \begin{cases} 1, & j = j' \\ \left|\dfrac{\sin(\pi(j-j')m/n)}{m\sin(\pi(j-j')/n)}\right|, & j \neq j' \end{cases} \tag{15}$$

(iii) The above two steps are repeated till c clusters are formed we define the support Likely-hood function,

$$p\left(\frac{y'}{I_k}\right) = \frac{\exp\left(-\dfrac{y'^H \Sigma_{I_k}^{-1} y'}{N_0}\right)}{\det\left(\Sigma_{I_k}\right)} \tag{16}$$

The quasi-orthogonality, can be defined as the following equation,

$$\hat{e}_I = \frac{I_k}{N_0}\Psi_I^H \Sigma_I^{-1} y' \approx \frac{I_k}{N_0}\begin{bmatrix} \Psi_{I_1}^H & \Sigma_{I_1}^{-1} \\ \Psi_{I_c}^H & \Sigma_{I_c}^{-1} \end{bmatrix} \tag{17}$$

The approximated expression for MMSE estimate of the impulse noise vector that can be calculated in a divide-and-conquer manner, by treating each cluster separately. This motivates the development of orthogonal clustering algorithm for impulse noise estimation which is described in the following.

6. ALGORITHM

A. Initial guess

The initial guess of the impulse noise locations is obtained. It consists of the following steps.

(i) Project y' on Fm to obtain y" = Fmy'.

(ii) The elements of y" with large *magnitude* determine the neighborhood of the position of the impulses.

B. Cluster formation

The clusters are constructed using the indices obtained from y" in the above step.

(i) Let β denote the index of the largest value of y". As it is very likely that an impulse is located in the neighborhood of the column indexed,

Ω={βl,βl±1,βl± 2,...,βl± (L−1 2)},

where L = 2L − 1, is the length of the cluster.

(ii) If two constructed clusters are overlapping the difference between the last index and the first index of two clusters is less than(L−1/2), they are joined into one big cluster.

We can use the Poisson approximation of the binomial probability mass function, i.e.,

P(J = c) ≈ (pn)c c! e−pn. (18)

C. Evaluating the impulse noise estimate for each cluster

By calculating the impulse noise estimate for each cluster For cluster i with indices Ωi and of length Li ≥ L,

(i) Calculate the support likelihood function for ,
P(Ji = Jmax i) ≈(pLi)Jmax i Jmax i ! e−pLi.

ii) Evaluate the estimate of the impulse noise using the following expression

$$\hat{e}_i = \frac{\sum_{N_i}\left(\frac{p}{1-p}\right)^{k_i} p(y'|I_i)\, \Psi_i \Sigma_{I_i}^{-1} y'}{\sum_{N_i}\left(\frac{p}{1-p}\right)^{k_i} p(y'|I_i)} \tag{19}$$

Where $\hat{e}_i$ consists of 0s at all positions except for Ωi and the summation is performed over Ni terms.

D. Evaluating the complete MMSE estimate $\hat{e}$

The following equation is,

$$\hat{e} = \frac{I_k}{N_0}\sum_{i=1}^{c} \hat{e}_i \tag{20}$$

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In the following section, we discuss how the complexity of the proposed algorithm can be reduced by the inherent structure of the partial DFT sensing matrix Ψ.

7. REDUCING COMPUTATIONAL COMPLEXITY

To estimate the MMSE $\hat{e}$ where, I is the union of disjoint clusters Ωi, in order to evaluate the equation,

$$\Psi_{j+k} = \Psi_{l+k} \odot \Psi_{jl} \quad k = 0,1, \ldots\ldots\ldots L-1, \tag{21}$$

$$y^{H} \Sigma^{-1}_{\Psi_{I}} y' = y'^{H}_{\Delta_{jl}} \Sigma^{-1}_{\Psi_{Il}} y'_{\Delta_{jl}} \tag{22}$$

where, $y'_{\Delta_{jl}} = \odot \Psi^{*}_{\Delta_{jl}}$, and

$$\det\left(\Sigma_{\Psi_{ij}}\right) = \det\left(\Sigma_{\Psi_{Il}}\right) \tag{23}$$

To pre-calculate the determinant values and inverse matrices for a set of supports of limited size clusters values to obtain the arbitrary clusters.

8. PERFORMANCE ANALYSIS

The performance Analysis is compared with the impulse noise estimation/cancellation, as well as with the received frequency domain OFDM after estimation is given by,

$$\hat{y} = DS_x \hat{d} + F(e - \hat{e}) + z \tag{24}$$

The OFDM blocks is corrupted by the impulse noise, this is represented by equation

$$R^{erasure}_{naive} = \frac{(1-p)^n}{n} \Sigma_{i \in S_d} \log\left(1 + \frac{|\lambda_i P_d|}{N_o}\right) \tag{25}$$

In a smart receiver method, the noise is estimated and subtracts the impulse noise,

$$R^{genie}_{smart} = \frac{1}{n} \Sigma_{i \in \alpha_d} \Sigma^{n}_{j=0} \binom{n}{j} p^j (1-p)^{n-j} \log\left(1 + \frac{|\lambda_i P_d|}{\sigma^2(j)}\right) \tag{26}$$

A. Approximate residual noise covariance using the orthogonality of clusters

To estimate orthogonality of clusters the equation is,

$$cov(e - \hat{e} \| I = I_j) \approx \frac{1}{\binom{n}{j}} \Sigma_{\Omega \| I \| = j} \Sigma^{j}_{l=1} S_{I_l} A^{-1}_{I_l} S^{T}_{I_l} \tag{27}$$

Finally, the sought conditional residual noise covariance is given by,

$$cov(v \| I = I) = F cov(e - \hat{e} \| I = I) F^{H} + N_o I \tag{28}$$

9. SIMULATION

In this system, we consider n = 1024 subcarriers per OFDM symbol and m = n 4 = 256 null carriers. The channel SNR is equal to 20 dB. The Bernoulli-Gaussian impulse noise has probability p ranging from 1×10−5 to 1×10−3 approximately one impulse per 100 DMT symbols.

A. Comparison for the uninformed receiver case

In this subsection, we compare the performance and runtime of the following receivers

- Naive receiver
- Genie-aided receiver is the upper bound bench-mark the case, MMSE is used for estimation of impulse amplitudes.
- Receiver that calculates the approximate residual noise the orthogonality of clusters.
- Proposed smart receiver (impulse noise estimation/compensation is based on orthogonal clustering algorithm).
- The smart receivers has different impulse noise estimation methods,
- (i) CR that uses CS based on convex relaxation which is used to find the impulse support.

$$\epsilon = \sqrt{N_o(n + \sqrt{2n})} \tag{29}$$

B. Comparison for the informed receiver case

- The calculation is based on convex optimization problem for genie smart. The binomial probability P is calculated based on the Poisson approximation with J =0 ,1,···,Jmax where the value of Jmax is computed based on the inequality P(J = Jmax) > 10−6.

C. Effect of the length of cluster L

- The cluster length is fixed at L =2, 2l−1=7for the current setting. The cluster lengths is consider as *L* =3, 5, 7, 9.
- The range of the cluster lengths is *L* > 3.

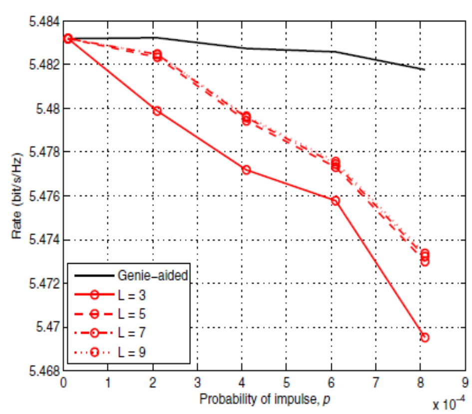

Figure-4. Effect of the cluster length on the performance of the proposed algorithm.

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D. Effect of the number of sensing carriers m

- The comparison of proposed algorithm with FBMP and OMP by the number of sensing carriers (*m*) is varied from 64 to 448 the range is $m \geq 256$.

E. Final simulation result

Simulation result is based on the mat lap output of the following stage. Actually impulse noise estimation is based on the cluster length. The following stages are based on the estimation of the impulse noise in the receiver side of the channel.

1. QPSK constellation map
2. Received QPSK constellation map
3. OFDM signal generation
4. Received OFDM signal
5. Impulse noise addition
6. Estimation of error
7. Performance evaluation

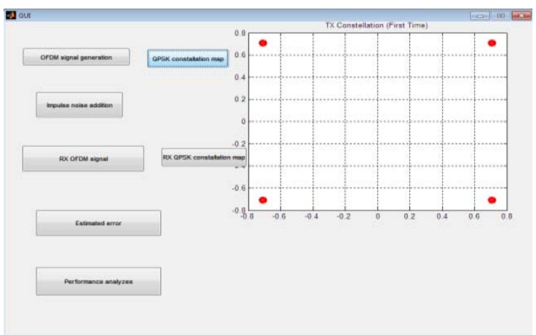

Figure-5. QPSK constellation map.

Description: Figure-5

Signal constellations with QPSK modulated OFDM symbols are plotted in REAL & IMAGINARY maps.

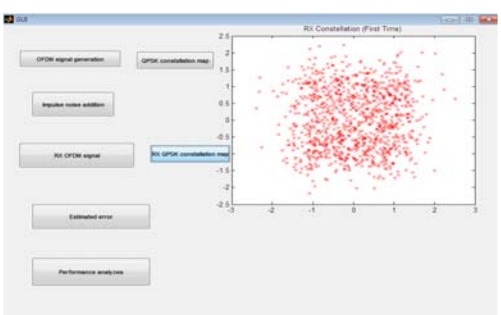

Figure-6. Received QPSK constellation map.

Description: Figure-6

Addition of impulse noise in OFDM symbols will lead worst case received constellations. Without estimation signal reconstruction is impossible here.

Description: Figure-7

This is the OFDM Signal Generation, in this we wanted to estimate the AWGN noise and impulse noise. This is the Transmitted OFDM Signal.

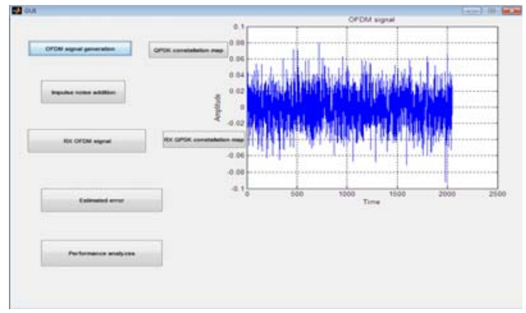

Figure-7. OFDM signal generation.

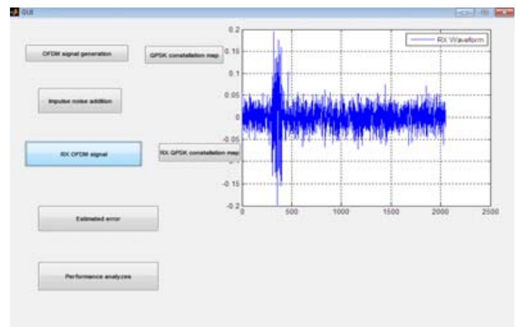

Figure-8. Received OFDM signal.

Description: Figure-8

This is the Received OFDM Signal. In this we wanted to estimate the impulse noise and AWGN .

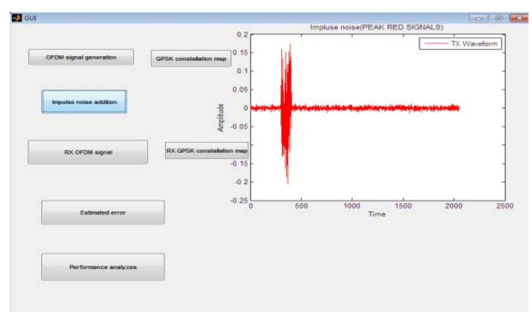

Figure-9. Impulse noise addition

Description: Figure-9

This is the addition of impulse noise in OFDM signal. Sparse nature of impulse noise in time domain is generated with non-uniform characteristics.

Description: Figure-10

Impulse estimated in each null tones is not uniform because of sparse nature of impulse noise.

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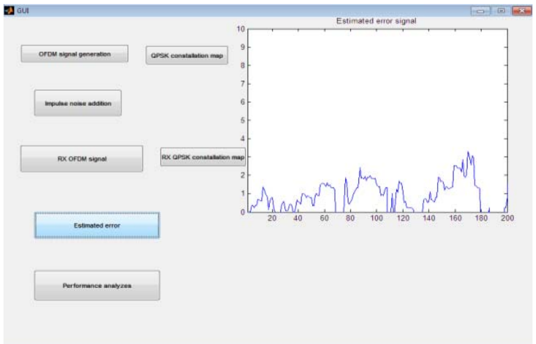

Figure-10. Estimation of error.

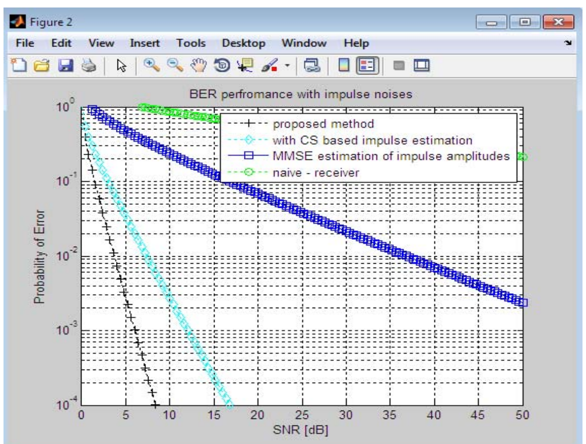

Figure-11. Performance evaluation.

Description: Figure-11

Here impulse estimated based OFDM signal reconstruction give better BER performance over conventional MMSE estimator based OFDM approach. Without noise estimation even with higher signal energy BER is not get reduced.

10. CONCLUSIONS

In this project, we propose a smart receiver that estimates and removes impulse noise in OFDM-based communications schemes (like DSL and PLC). Such intelligent receivers have significant advantage with respect to spectral efficiency, speed, and simplicity, when compared to the conventional retransmission techniques proposed in many standards. The impulse noise is assumed to be sparse and thus any sparse reconstruction algorithm can be utilized at the receiver. Unlike convex relaxation methods or matching pursuit algorithms for sparse reconstruction, the proposed approach makes a collective use of the structure of the sensing matrix (partial DFT matrix) in OFDM systems and a priori information of the impulse noise distribution, resulting in a fast and efficient algorithm. Simulation results demonstrate the superior performance of the proposed algorithm.

11. FUTURE SCOPE

Impulse estimation based approach leads signal distortion in noise free region or regions with Gaussian noise. Here we are going to produce clipping which can be applied to the received vector to reduce the power of the impulsive noise by limiting the maximum signal value. With Viterbi algorithm based channel decoder as simplest receiver and reed Solomon based channel decoder as a complex decoder for robust OFDM system against any level of impulse noise.

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