An Efficient Method for Mitigating Impulsive Interference in OFDM Systems

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Abstract- The rapid growth of mobile communications and wireless internet access has produced a strong demand for inexpensive, portable, and high data rate wireless transceivers working in variety of environments. Most of the transmission systems experience degradations, such as attenuation, noise, interference, multipath fading, time variation, and non-linearity. The aim of this paper is to investigate the effect of impulsive interference on the performance of the OFDM (orthogonal frequency division Multiplexing) system. A method of improving OFDM receiver performance in an impulsive noise environment is to precede a conventional OFDM demodulator with blanking nonlinearity. Although blanking nonlinearity removes impulsive interference reliably, it possesses various drawbacks for OFDM based systems. These drawbacks can be overcome by using three techniques. In first technique, advancements to the conventional blanking nonlinearity are introduced which is referred as adaptive blanking nonlinearity. The second technique is the combining technique where the received signal is combined with the signal after the blanking nonlinearity. The third technique is the iterative technique. Performance in terms of bit error rate and signal to noise ratio is compared with and without interference mitigation and with the classical blanking nonlinearity method showing significant improvements.

I. INTRODUCTION

Orthogonal Frequency Division Multiplexing

Orthogonal Frequency Division Multiplexing (OFDM) is a digital multi carrier modulation scheme, which uses a large number of closely spaced orthogonal sub-carriers. A single stream of data is split into parallel streams each of which is coded and modulated on to a subcarrier. Each sub-carrier is modulated with a conventional modulation scheme (such as quadrature amplitude modulation (QPSK) or phase-shift keying) at a low symbol rate, maintaining total data rates similar to conventional single-carrier modulation schemes in the same bandwidth. These subcarriers are regularly spaced in frequency, forming a block of spectrum. The frequency spacing and time synchronization of the subcarriers is chosen in such a way that the subcarriers are orthogonal, meaning that they do not cause interference to one another. Despite the subcarriers overlap each other in the frequency domain.

OFDM can be easily implemented using Fast Fourier Transforms (FFT), an efficient digital signal processing (DSP) realization of DFT. OFDM has developed into a popular scheme for wideband digital communications, whether wireless or over copper wires, used in applications such as digital television and audio broadcasting, DSL broadband internet access, wireless networks, and 4G mobile communications.

Orthogonal frequency division multiplexing (OFDM) is a popular method for high data rate wireless transmission. OFDM may be combined with antenna arrays at the transmitter and receiver to increase the diversity gain and/or to enhance the system capacity on time-variant and frequency-selective channels, resulting in a multiple-input multiple-output (MIMO) configuration.

PROBLEM DEFINITION

Generally wireless systems are susceptible to interference caused by other systems operating in the same frequency range. This interference impact is expected to increase over time with the implementation of new systems in conjunction with the scarcity of unused spectrum. In many OFDM applications, the interference influence is small and well compensated by the spreading effect of the Fast Fourier transform (FFT) in conjunction with channel coding.

However, in case of strong interference or many different interference sources, the transmission performance of the OFDM system will degrade considerably if no countermeasures are taken. This issue puts the mitigation of interference in the focus since, in many applications the interference occurs as short impulses.

In aeronautical communications, L-band digital aeronautical communications system type1 (LDACS1) will be exposed to impulsive interference from distance measuring equipment (DME).

II. LITERATURE SURVEY

Performance Analysis and Optimization of OFDM Receiver with Blanking Nonlinearity in Impulsive Noise Environment

A simple method of improving OFDM receiver performance in an impulsive noise environment is to precede a conventional OFDM demodulator with blanking nonlinearity. This method is widely used in practice since it is efficient and very simple to implement. However, performance analysis of this scheme has not yet appeared. In this paper, we study performance of the OFDM receiver with blanking nonlinearity in the presence of impulsive noise. Closed form analytical expressions for the SNR at the output of blanking nonlinearity and the optimal blanking threshold that maximizes SNR are derived. Simulation results are provided that show good agreement with theory if the number of OFDM subcarriers is sufficiently large.

III. EXISTING SYSTEM

Orthogonal frequency division multiplexing (OFDM) systems often exposed to impulsive interference that originates from ignitions of passing vehicles, or other systems operating in the same frequency range. OFDM systems can cope relatively well with moderate impulsive interference but for high interference power the performance of the system is affected due to which mitigation techniques are required.

A common approach for mitigating the impact of impulsive interference is to apply a memory less blanking nonlinearity (BN) at the receiver input prior to the conventional OFDM demodulator. Blanking nonlinearity (BN) is one of the most widely used methods because it is easy to implement, while providing a remarkable performance gain, compared to a conventional OFDM receiver.

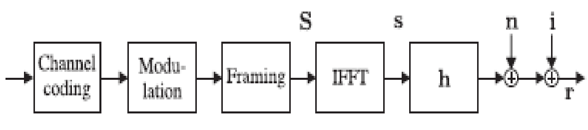

Fig. 1. Block diagram of OFDM transmission, including transmitter block, channel model, and impulsive interference.

A very low value of threshold usually blanks the useful OFDM signals unaffected by impulsive interference and a high value of threshold is unable to detect interference affected signals. The perfect blanking threshold value depends on the interference model. This value has to be chosen properly, as it is a trade-off between removing interference and preserving the useful OFDM signal.

An optimal threshold for the BN can be calculated by estimating the SINR after the BN, which depends on the blanking threshold T^{BN}. By maximizing this SINR, i.e., searching for the T^{BN} which leads to the highest SINR, optimal blanking threshold can be obtained as

$$T^{BN}_{opt} = \arg (\max (SINR(T^{BN}))) , T^{BN} > 0$$

DRAWBACKS OF EXISTING SYSTEM

The issues of the existing system are summarized in the following.

1.The determination of the BT is a sensitive task. The high peak-to-average power ratio (PAPR) of OFDM signals makes differentiation of interference pulses from OFDM signal peaks a challenging task. Correspondingly, a poorly chosen BT may impair the OFDM signal significantly.

2.The entire received signal is discarded during a blanking interval despite the fact that only a fraction of the spectrum of the OFDM signal might be affected by interference. This feature leads to a waste of useful OFDM signal energy.

3. The blanking of the OFDM signal by the BN introduces inter carrier interference (ICI) between the different subcarriers in the frequency domain. This effect limits the performance of the BN.

IV. PROPOSED SYSTEM

The orthogonal frequency division multiplexing (OFDM) receiver performance in an impulsive noise environment can be improved by foregoing a conventional OFDM demodulator with blanking nonlinearity. Several algorithms have been developed to soothe the drawbacks of the BN. The performance of the transmission is improved by applying these algorithms separately but the achievable gain is limited. In this work, an OFDM receiver concept in which algorithms can be combined beneficially in such a way that both the time and frequency domain characteristics of the impulsive interference are analyzed and subsequently exploited is presented.

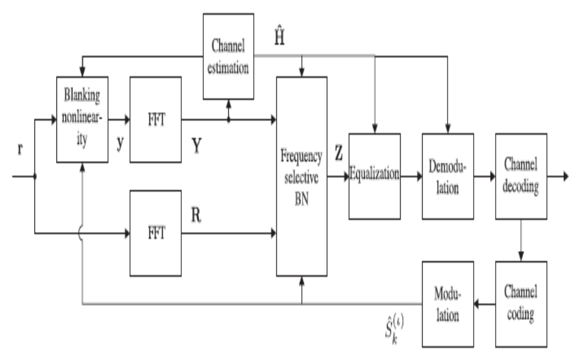

Fig.2: Block diagram of iterative OFDM receiver including proposed interference mitigation.

Adaptive Blanking Nonlinearity

The existing approach only accounts for AWGN and is assumed that the impulsive interference has a constant power spectral density (PSD). In this work, we show how these two limitations can be overcome.

The proposed algorithm does not require any information regarding the impulsive interference. It exploits the structure of the received signal, the OFDM signal power P_s, and the AWGN power N_0 before BN. Both power values are known in general or can be estimated easily in an OFDM receiver.

This approach estimates SINR after BN, depending on T^{BN}. The given optimization method depends on a reliable estimation of the subcarrier SINR after BN. Two parameters are defined for deriving an expression for SINR(T^{BN}).

1. Remaining impulse interference after BN
2. The attenuation factor.

Frequency-Selective Blanking Nonlinearity

The proposed FSBN scheme profits from combining the received signal with the signal after the BN as shown in Fig. The approach is realized by first detecting the interference at each subcarrier using a new Neyman–Pearson-like testing procedure.

Provided that interference has been detected, both the received and the blanked signal are subsequently optimally combined to maximize the SINR for each subcarrier. In this way, the proposed algorithm compensates losses due to falsely blanked OFDM signal samples that are not corrupted by interference. In addition, the blanking of the OFDM signal is restricted to subcarriers that are actually affected by impulsive interference.

- The FSBN algorithm assuming a fixed predefined BT is defined.
- The BT calculation derived for BN, has to be adjusted to FSBN
- The potential gains of FSBN in an iterative loop.

Algorithm

Consider the block diagram of the OFDM receiver structure shown in Fig. The block diagram illustrates that the FSBN contains both BN block and frequency (FSBN block) domain interference mitigation approach.

The combined signal Z is computed to maximize the SINR for each subcarrier, which is explained in the following. This algorithm does not rely on a known shape or model of the interference, neither in the time nor frequency domain. This is classified into two stages as detailed.

1) Detection of interference for each sub-carrier;
2) Estimation of SINR by combining both signals optimally.

Stage I: Interference Detection

Detection and estimation of the interference power at each subcarrier is done by assuming that the impulsive interference I_k in the frequency domain is Gaussian distributed for an individual subcarrier k. This approximation is valid independently of the structure of the impulsive interference due to the spreading effect of the FFT.

The signal Y_k after BN and FFT is represented as follows

$$Y_k = KH_kS_k + N'_k + D_k$$

The distortion term D_k accounts for the ICI induced by BN, and N_k' denotes AWGN after BN. Equations allow us to define the FSBN indicator signal as follows:

$$\Delta Y_k = R_k - \frac{Y_k}{K} = I_k + \left(N_k - \frac{N'_k}{K}\right) - \frac{D_k}{K}$$

Denoting the AWGN part of the FSBN indicator signal by

$$\Delta N_k = N_k - \frac{N'_k}{K}$$

FSBN distortion term is defined as

$$D'_k = \Delta N_k - \frac{D_k}{K}$$

FSBN indicator signal is written from (4.13) as

$$\Delta Y_k = I_k + D'_k$$

The signal ΔY_k is a useful indicator to determine whether the k^{th} subcarrier is affected by interference or not.

- If $I_k = 0$, ΔY_k equals D_k' only.
- If $I_k \neq 0$,ΔY_k will include the combination of D_k' and impulsive interference I_k.

Stage II: Estimation of SINR

Under the assumption that I_k and D_k are uncorrelated, the interference power at the k^{th} subcarrier can be computed

$$|I_k|^2 = \begin{cases} |\Delta Y_k|^2 - var(D'_k), & if\,|\Delta Y_k| \geq T_{H,K} \\ 0, & else \end{cases}$$

The combined subcarrier signal is calculated which is an optimal combination of R_k and Y_k that maximizes the SINR given as

$$Z_k = w_kR_k + (1 - w_k)Y_k$$

Where $w_k \in [0, 1]$ is a weighting factor. The SINR of the combined signal Z_k as a function of the weighting factor w_k, can be obtained as

$$SINRZ_k = \frac{|H_k|^2 P_s (w_kR_k + (1 - w_k)K)^2}{{w_k}^2|I_k|^2 + (1 - w_k)^2 K(1 - K)P_H P_s}$$

Adjustment of Blanking Threshold Calculation

The adaptive BT calculation has to be adjusted while applying to FSBN. The BT is obtained by maximizing the SINR after BN. In this section we show how the calculation of the BT T^{BN} is adjusted to frequency-selective interference.

After the blanked signal is combined with the received signal, the threshold T^{BN} is obtained to maximize SINR after the combination of both signals.

The SINR calculation requires knowledge of the subcarrier interference power $|I_k|^2$. However, such knowledge is not available at BN. In the following, it is shown how $|I_k|^2$ can be approximated and, subsequently, how an adaptive BT can be calculated for FSBN. The FSBN with adaptive BT calculation is referred in this section as adaptive FSBN.

To calculate the remaining impulsive interference by it is assumed that the impulsive interference spreads equally over all subcarriers. In reality, this assumption might not always be valid, and merely certain subcarriers might be affected by interference.

Here, we show how the remaining subcarrier impulsive interference PI can be approximated for frequency-selective impulsive interference.

V. IMPLEMENTATION AND RESULTS

The performance of the proposed algorithm is evaluated by choosing LDACS1 OFDM system which is exposed to impulsive interference from DME systems. The operating frequency of LDACS1 is 994.5MHz and it occupies a bandwidth of 625 kHz with N=64 subcarriers. For channel coding, Reed- Solomon code with rate $r_{RS}\approx 0.9$ and a convolution code with rate $r_{CC}\approx 1/2$ are used. Coded bits are modulated by using quadrature phase shift keying (QPSK). Gaussian- shaped impulse pairs are generated by DME stations transmitting at $\Delta f_c = \pm 0.5$ MHz frequency offset compared with the LDACS1 carrier frequency.

These impulse pairs occur in short duration but high power is interfered in an OFDM signal and partially overlapping with the LDACS1 bandwidth which leads to a frequency-selective impulsive interference. This mainly affects the edges of theLDACS1 bandwidth. To evaluate the interference scenario four DME stations are taken into account which is characterized in Table .

The individual impulse pairs are modeled by independent Poisson processes which results in quasi-random occurrence of DME impulses. The OFDM symbols may be affected by impulse pairs form all four DME stations or by fewer DME stations or not affected by interference at all. This causes a variety of different interference conditions with which our proposed algorithms have to cope. The signal-to-interference ratio (SIR) is defined as the ratio of P_s and the peak power P_i of DME impulses. The SNR is defined as P_s/N_0. An increase in SNR corresponds to an increase in OFDM signal power in real systems. This is taken into account when calculating the SIR by adding the SNR. When designing LDACS1, very high frequency channel models have to be adapted to the L-band which is used for our investigation. These aeronautical L-band models have been derived mainly based on geometrical considerations.

Table 1: Parameters of Interference Scenario

Station	Δf_c[MHz]	SIR[dB]	Impulse Pair Rate [1/s]
DME 1	-0.5	-18.7+ SNR [dB]	3600
DME 2	-0.5	-17.2+ SNR [dB]	3600
DME 3	-0.5	-2.9+ SNR [dB]	3600
DME 4	+0.5	-23.3+ SNR [dB]	3600

ADAPTIVE BN

To determine the impact of frequency selective impulsive interference on the bit error rate (BER) performance for different ways of determining BT. BER versus SNR is plotted as shown in Figs. It shows the performance of a transmission without interference and a transmission with interference but without BN. A comparison of fixed BT of T^{BN} = 3.5 with the adaptive BT calculation is done. This calculation is performed for M = 1 and M = 8 bins.

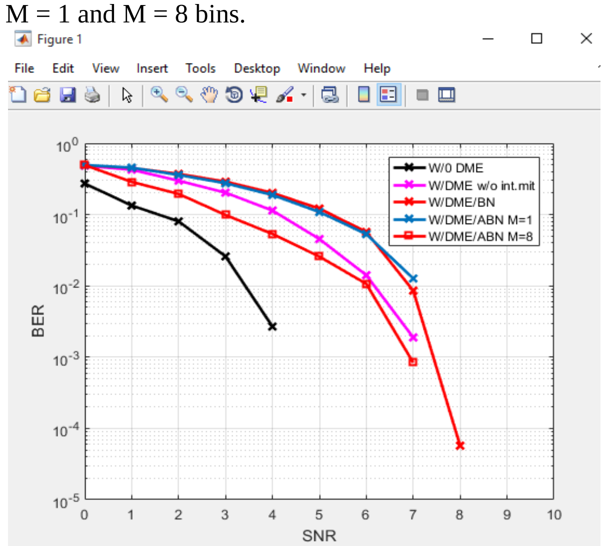

Fig.1: BT Calculation on coded BER of LDACS1 Tx.vs SNR for AWGN channel and DME interference.

The performance of the system is influenced by the adjustment of BT calculation to frequency-selective interference. BER versus SNR is plotted in Fig. in which DME interference is replaced by gated Gaussian interference (GGI), accounting for interference with a constant power spectral density (PSD). For GGI, $\beta^{GGI} = 0.1$, $\zeta = 2$, and SIR = −15 dB are considered.

The BT calculation is done by segmenting the OFDM transmission bandwidth into M = 8 bins and assuming that we have perfect knowledge of the CTF

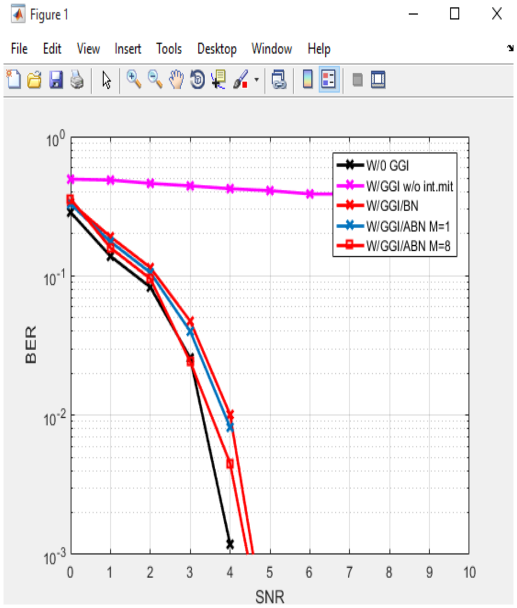

Fig.2: BT Calculation on coded BER of LDACS1 Tx.vs SNR for AWGN channel and GGI interference

Adaptive FSBN

The performance of the FSBN algorithm is evaluated by exposing LDACS1 transmission to the DME interference in an ENR channel. The coded BER of an LDACS1 transmission versus the SNR is given in Fig. An AWGN channel is applied to separate distorting transmission channel effects from interference effects. A moderate performance gain is achieved by BN with a fixed threshold of $T^{BN} = 3.5$ when compared with a transmission without interference mitigation. When the adaptive BN with M=1 is applied no remarkable performance gain is achieved compared with a transmission without interference mitigation and compared with the fixed BT, the performance is even slightly worse for high SNR due to the improper estimation of the interference power.

By segmenting the transmission bandwidth into M = 8 bins and adjusting the threshold calculation, a huge performance gain of 3 dB is obtained compared with a transmission with a fixed BT of $T^{BN} = 3.5$.

The performance of the system is influenced by the adjustment of BT calculation to frequency-selective interference. BER versus SNR is plotted in Fig. 6.2 in which DME interference is replaced by gated Gaussian interference (GGI), accounting for interference with a constant power spectral density (PSD). For GGI, $\beta^{GGI} = 0.1$, $\zeta = 2$, and SIR = −15 dB are considered.

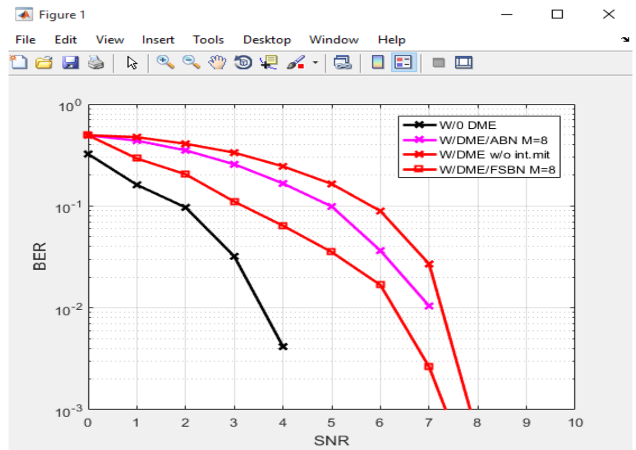

Fig.3: Comparison of BN and FSBN. Coded BER versus SNR of LDACS1 transmission, QPSK modulation, ENR channel, DME interference, adaptive BN and FSBN with M=8

Iterative Receiver Structure

The coded BER of an LDACS1 transmission versus SNR is shown in Fig. 6.4by considering the potentials of iterative receiver structure. Interference mitigation is done by considering adaptive BN with M = 8 and GGI with SIR = −5 dB, $\beta^{GGI} = 0.1$, and $\zeta = 1$ in the TMA channel and 2-D linear interpolation for CE.

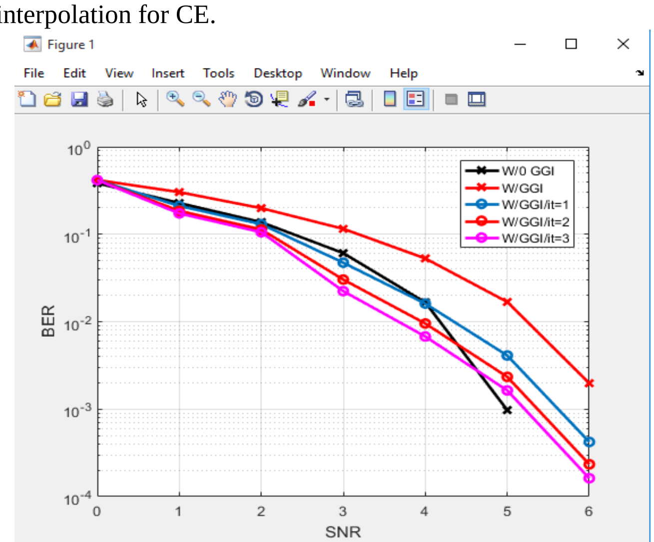

Fig.4: Coded BER versus SNR of LDACS1 transmission, QPSK modulation, iterative receiver, TMA channel with GGI

No estimates of the channel coefficients are available for the calculation of the BT for $\iota = 0$ in the BN block, the BER tends toward an error floor. However, for $\iota > 0$, a significant iterative performance gain can be observed. The performance is further improved in second iteration and third iteration by the influence of a priori information for BN. The gap between actually obtained and perfect a priori information is 1.8 dB and is mainly due to the imperfect CE by 2-D linear interpolation.

Comparison

For interference mitigation, consider adaptive BN and adaptive FSBN with M=8 bins having DME interference along with ENR channel The coded BER versus SNR is shown in Fig.

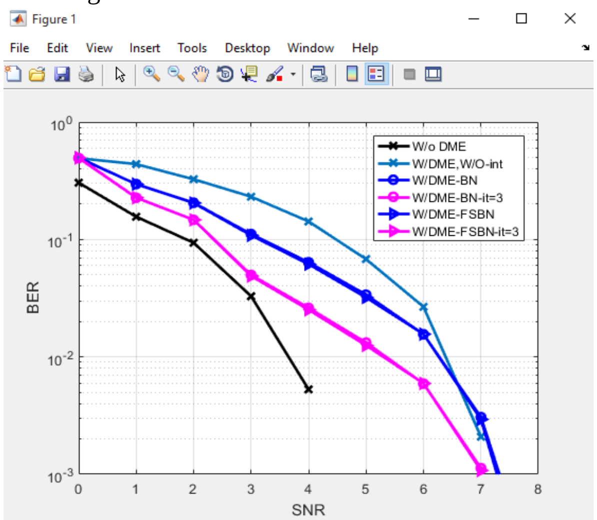

Fig.5: Coded BER versus SNR of LDACS1 transmission, QPSK modulation, iterative receiver, ENR channel, DME interference, adaptive BN and FSBN with M=8

These results illustrate the potentials of the proposed efficient BN. If no iterative loop is applied, a significant gain by BN and an additional gain of 1.2 dB by FSBN are observed. In the case of i=3 iterations both algorithms benefit from priori information.

VI. CONCLUSION

In this paper, a method for mitigating impulsive interference in OFDM systems is proposed. The proposed method is an advancement of conventional blanking nonlinearity and does not require any information regarding interference characteristics. This algorithm can be potentially used with any type of impulsive interference. The performance of the proposed method is presented in comparison with the classic blanking method showing a significant gain in terms of bit error rate. Simulations showed that, depending on the type of interference considered, different measures lead to considerable performance gain with a relatively low increase of computational complexity compared with conventional BN. These two facts make proposed method applicable to a wide range of OFDM systems.

VII. FUTURE SCOPE

The overall performance of the OFDM receiver can further be increased by cancelling inter carrier interference which is introduced by blanking nonlinearity and by combining peak to average power ratio reduction techniques with the proposed scheme.

VIII. REFERENCES

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