PERFORMANCE EVALUATION OF ADAPTIVE RECEIVERS FOR UWB COMMUNICATION

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Abstract

UWB (Ultra Wide Band) is a radio technology used at very low energy levels for short-range, high-bandwidth communications using a large portion of the radio spectrum. But MAI (Multiple Access Interference) degrades the performance of UWB systems. To suppress this, an α-stable model along with Fama/Roll-McCulloch parameter estimation technique is used. This model adapts to the noise and interference in the environment and hence it forms a robust technique for adaptive receiver designs. But this technique shows BER performance clearly only in high SNR region. Hence matched filter techniques are proposed here. From simulation results, it is verified that the proposed method provides better BER than the linear and myriad filter detectors.

Key Words: *Detector, Multiple Access Interference (MAI), Ultra Wide Band (UWB), α-stable model*

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1. INTRODUCTION

Ultra Wide Band (UWB) is a Radio Frequency (RF) technology that transmits data in binary form using extremely short duration impulses over a wide spectrum of frequencies. It has a marvellous quality of delivering data over 10 to 100 meters and does not require any kind of dedicated radio frequency, so is also known as carrier-free, impulse or base-band radio. A UWB system is defined as any radio system that has a 10-dB bandwidth larger than 25 percent of its center frequency, or has a 10-dB bandwidth equal to or larger than 1.5 GHz if the center frequency is greater than 6 GHz. A radio with such a extremely wide bandwidth implies its ability to distinguish arriving paths with sub-nanosecond resolution.
Ultra-wideband may be used at very low energy levels for short-range, high-bandwidth communications using a large portion of the radio spectrum. It is a technology for transmitting information spread over a large bandwidth (>500 MHz) and also should be able to share spectrum with other users. Ideal targets for UWB systems are low power, low cost, high data rates, precise positioning capability, and extremely low interference. An ultra wide band device transmits sequences of information carrying pulses of very short duration about 0.1 to 2 nanoseconds, thus spreading the signal energy from near DC to a few Giga Hertz. Common pulse shapes include Gaussian, Laplacian, Rayleigh or Hermitian pulses. Data modulation is typically based on PPM. Each pulse in a pulse-based UWB system occupies the entire UWB bandwidth.

While UWB has many reasons to make it an exciting and useful technology for future wireless communications and many other applications, it also has some challenges that must be overcome for it to become a popular and ubiquitous technology. The various challenges include multiple access interference, accurate synchronization and channel parameter estimation.

Multiple Access Interference (MAI) is a performance limiting factor in many wireless communication systems. MAI is generally modeled by a Gaussian random variable owing to a central limit theorem. However, in many cases a Gaussian model is not suitable for the MAI. In multiple access systems where the interferers are scattered in a Poisson field, the MAI was shown to be α-stable distributed. MAI is known to be impulsive and the PDF has a heavier tail than the Gaussian PDF. Therefore, it is perceptive to pertain diverse impulsive noise models to the distribution of the MAI to improve detection performance.

In this paper, practicable solutions for the above mentioned problems are proposed. We present adaptive Rake receivers, suitable for practical implementations, based on the myriad filter technique. A proper way to apply the α-stable model for detection purposes and a technique to estimate the receiver tuning parameter are introduced. The proposed receivers can automatically adjust to changes in user density, path loss exponent, and noise level. They are also not sensitive to receiver parameter estimation errors.

The remainder of the paper is organized as follows. Section II discusses several existing linear and non linear detectors. Section III describes MAI model with α-stable model and the parameter estimation technique. The conclusions are drawn in Section V.

2. RELATED WORK

In this section, we present several existing linear and nonlinear detectors for signals contaminated by different additive white noises.

N. C. Beaulieu and S. Niranjayan proposed a soft-limiting receiver when the signal is immersed in a mixture of additive Laplace and Gaussian noise. A correlation receiver is optimal if the detection problem is that of detecting a known signal in additive Gaussian noise. However, the correlation receiver for UWB will not be an optimal receiver unless the multiple access interference component in the decision metric can be accurately approximated as Gaussian. Therefore, improved UWB receiver structures are developed which can perform better in multiple access environments.

The generalized Gaussian model, Laplacian model and Cauchy model are some of the important and tractable models considered in [4]. In particular, the Laplacian model results in a simple receiver design and in addition parameter estimation and performance analysis are tractable [5], [6]. In [7], three classes of non-Gaussian noise models were introduced (known as Middleton's class A, B and C models) to model electromagnetic radio noise. These models can be physically interpreted and fit well with various measurement data. However, the Middleton models are generally too complicated for practical detection applications.

The Gaussian mixture model is also often used in modeling impulsive noise; it is mildly popular due to its simplicity. References [8] and [9] list many other non-Gaussian noise models suitable for modeling impulsive noise. However, not all of them are practically attractive for receiver design. Signal detection in α-stable noise is generally complicated due to the lack of a closed-form solution for the α-stable PDF.

The Cauchy distribution is a special case of the α-stable distribution with $\alpha = 1$. It is the widely recommended suboptimal detector for α-stable noise. However, the Cauchy detector is not robust to varying values of the parameter α (i.e., varying levels of impulsiveness) and is not efficient for mixed α-stable plus Gaussian noise environments. A different signal processing technique, called the "myriad filter", was proposed in [11], [8], [9], for non-linear signal processing in α-stable noise. However, determining the tuning parameter of the myriad filter during operation still remains a challenge.

Juan G. Gonzalez and Gonzalo R. Arce presented a large number of filtering algorithms used in practical applications which are limited to the cases of Gaussian noise presenting serious performance degradation in the presence of impulsive contamination. The myriad filter is defined as a running-window filter outputting the sample myriad of the elements in the window. Sample myriad involves the free tunable parameter k. Here k is referred to as the linearity parameter of the myriad. Myriad equips the filter with the ability to operate with high efficiency throughout the entire range of impulsiveness of the α-stable family.

3. SYSTEM MODEL

A TH-UWB system is chosen for illustration. PAM is used here. The mono-pulse shape used for this work is the 2*nd*-order Gaussian monocycle found in [12]. One symbol consists of *Ns* pulses and hence symbol duration is equal to *Ns Tf*. The α-stable distribution is a good candidate for a MAI model. However, it does not have a simple closed-form PDF expression except for three known special cases.

The distribution becomes a symmetric distribution when $\beta = 0$ and $\mu = 0$. Since the distribution of MAI is generally symmetric, the SαS is a suitable candidate for modeling. Since the distribution of MAI is generally symmetric, symmetric α-stable distribution (SαS) is a suitable candidate for modeling. The SαS has the characteristic function as

$$\Phi_{S\alpha S}(\omega) = \exp(-\zeta^{\alpha}|\omega|^{\alpha}) \qquad (1)$$

A two-dimensional Poisson model with user density λ is assumed for the spatial scattering of users. The scattering model is only involved in determining the large scale fading. Poisson point process is conventionally used in modelling user arrivals.

A 2-D or 3-D Poisson point process on a plane or on a space can be used to model the scattering of active users in a wireless communication network. The scattering model determines large scale fading. The channel's small scale fading, and shadowing effects are modeled by the UWB channel model. Distribution parameters of the Gaussian and the Laplacian models are evaluated directly using the variance of the MAI samples. The SαS model parameters are evaluated using the Fama/Roll-McCulloch method. Samples of MAI are collected when the user positions are fixed but arbitrary.

The Fama/Roll- McCulloch parameter estimation method is chosen as the best method for model parameter estimation because of the following reasons:

1. Provides a consistent estimate.
2. The computational complexity of the CF based method is high.
3. Captures the distribution's tail behaviour with α-stable model well.
4. Minimizes the effect of the singularities.
5. Most robust and reliable estimator with samples of MAI in different channel conditions.

No optimal detection or estimation algorithms are known for signals immersed in general SαS noise. However, the myriad filter exists as a suboptimal method for estimating the location parameter of an α-stable process. Myriad filter location estimator is used to develop a heuristic UWB multiple access receiver and verify the receiver performance in AWGN channels. Here the design is extended to typical UWB channels with a robust receiver parameter estimation technique.

A myriad filter estimates the location parameter, μ of a SαS distribution based on observations (samples) $\{x_i\}_{i=1}^{N}$ as

$$\mu = \text{myriad}\ [K; x_1, x_2 \dots \dots, x_N] \qquad (2)$$

Where one has to select a suitable value of *K* known as the tuning or linearity parameter The estimator becomes a mean filter when K$\rightarrow \infty$ and is optimal for Gaussian noise; it becomes a mode filter when *K* approaches zero which is optimal for very impulsive conditions. When K=ζ the estimator becomes the optimal filter for Cauchy noise. The α-stable model for the MAI is useful in our signal detection problem for the following four reasons.

1. To represent varying levels of heaviness.
2. To accurate approximate the conditional distribution.
3. The structure of the myriad filter detector is simple and easy to implement.
4. The myriad filter detector receiver parameters estimates work well for detection.

Simulation results obtained under fading channel conditions are used to produce empirical estimates of the actual PDF of the MAI and the distribution parameters of some candidate models, including the α-stable model. Distribution parameters of the Gaussian and the Laplacian models are evaluated directly using the variance of the MAI samples. The SαS model parameters are evaluated using the Fama/Roll-McCulloch method.

The α-stable PDF was calculated using the software tool STABLE available at [18]. Samples of MAI are collected when the user positions are fixed but arbitrary. The impulsiveness of the MAI PDF increases with increasing path loss exponent, *m*. The larger the value of *m* the smaller the value of α and the heavier the tail of the MAI PDF. Fama/Roll-McCulloch parameter estimation method is chosen as the best method for model parameter estimation. No optimal detection or estimation algorithms are known for signals immersed in general SαS noise. The stable noise model parameters, α, ζ, are estimated by the Fama/Roll-McCulloch estimator.

A receiver with *Lc* rake fingers generates the partial decision statistics Since the SαS model can easily represent various levels of impulsiveness, and to obtain a simple adaptive receiver, the sum is modelled by a SαS process. Assuming perfect channel information is available the decision metric is computed.

4. PERFORMANCE ANALYSIS

The simulation model is implemented by using MATLAB tool. The receivers used for comparison are linear detector, myriad filter detector and matched filter detector. BER is calculated in *dB* and *SNR* = *Es/N*0.The following parameter values are assumed in simulation Nh = 8, Ns = 8, Nc = 20, Lc = 5, L = 20, Tf = 20 ns, and Tc = 0.9 ns.

From Fig.1, it shows that as SNR goes on increasing, the BER performance of the three detectors goes on decreasing. But matched filter shows the best performance in terms of lower bit error rate. In Fig.2, Ns denote the number of frames. When Ns increases from 2 to 16, the BER performance decreases. Here also matched filter performs better than the other two detectors. Fig.3 denotes No. of users versus BER of the three detectors. As the No. of users is increased in a UWB channel, matched filter detector shows a better decrease in BER.

For any value of *Ns* > 1, matched filter receiver outperforms the linear receiver and myriad filter detector showing the best performance. The matched filter detector has the best BER performance regardless of the values of *Nu*, *Ns*, and λ.

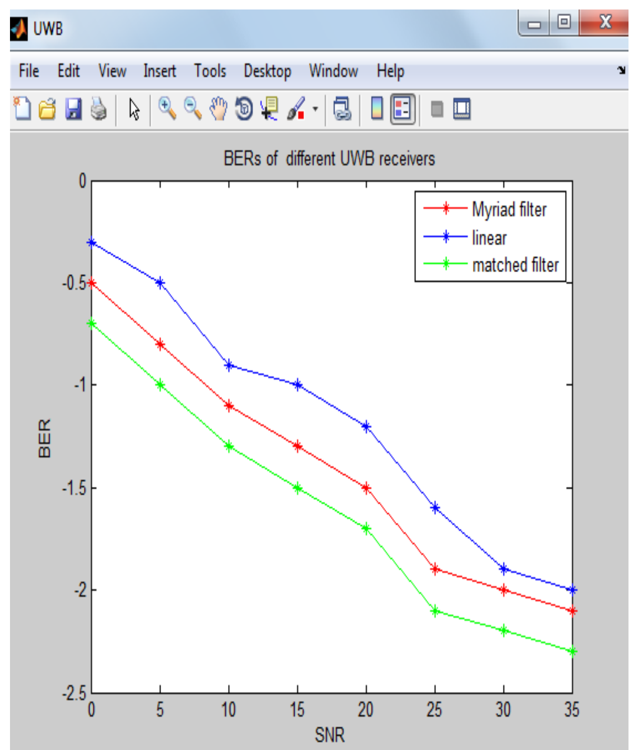

Fig-1: SNR vs. BER

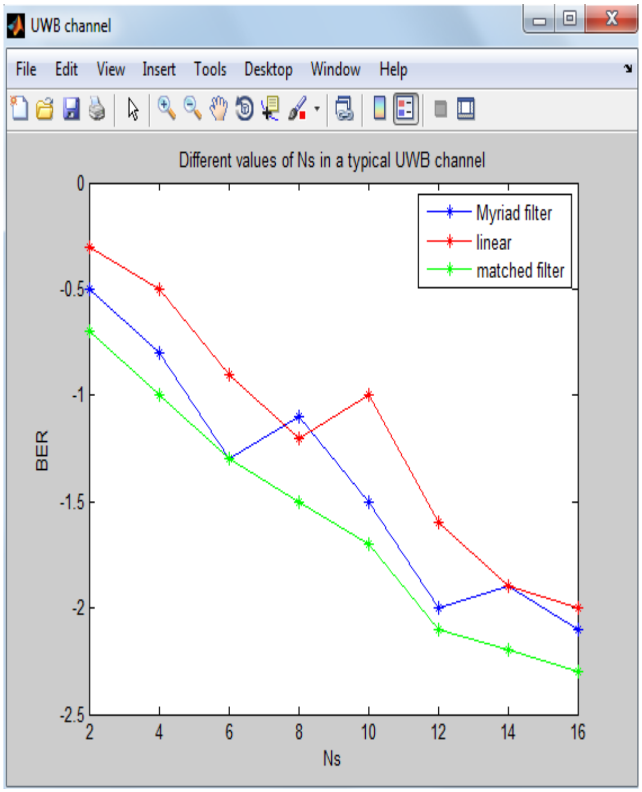

Fig-2: Ns vs. BER

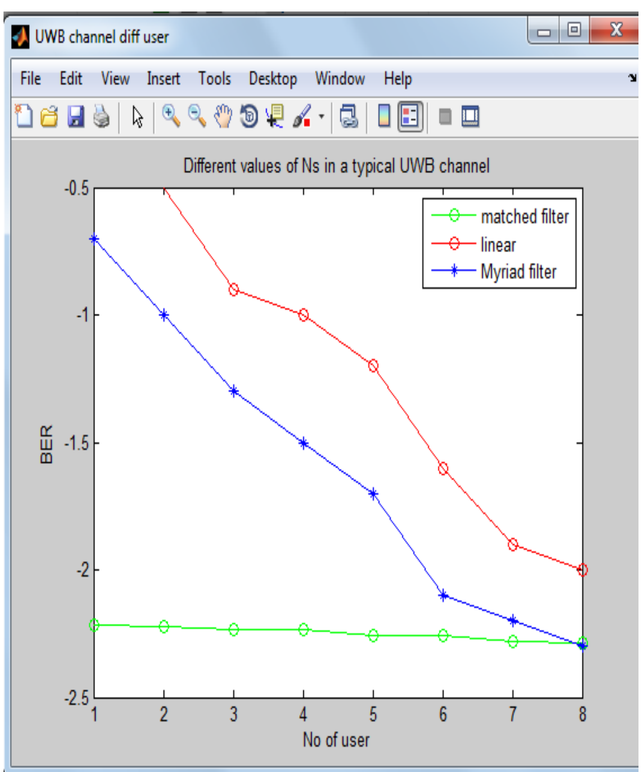

Fig-3: No. of User vs. BER

5. CONCLUSIONS

To suppress the multiple access interference, additive noise and interference is modeled by an α-stable distribution. α-stable model is preferred due to its versatility in modelling impulsive noise. Adaptive nonlinear rake receiver designs based on this model were proposed and studied for ultra-wide bandwidth multiple access communications. These receivers adapt to changes such as user density, channel power decay exponent, and ambient noise level. They also perform well under estimation errors in the receiver parameters.

Simulation results under a realistic UWB channel model and Poisson user scattering assumptions showed that the α-stable model is the best model for the multiple access interference. However the BER improvement is not seen in the low SNR region. The improvement is clearly seen in the high SNR region. This is because at low SNR the total additive noise is less impulsive due to the dominance of the Gaussian noise.

The proposed adaptive nonlinear receiver designs along with matched filter techniques show much better BER and capacity performance compared to the existing conventional linear and myriad filter receiver.

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