IEICE Electronics Express, Vol.8, No.18, 1505–1510

An improved UWB receiver employing generalized normal-Laplacian distribution model

Jinyoung An and Sangchoon Kim[a)]
Department of Electronics Engineering, Dong-A University
840 Hadan 2-Dong, Saha-Gu, Busan, 604–714, South Korea
a) *sckim@dau.ac.kr*

Abstract: The generalized normal-Laplace (GNL) distribution is employed to reflect the heavy-tailed and impulsive nature of the multiple access interference (MAI) plus AWGN noise in ultra-wideband (UWB) systems. To accurately represent the impulsive feature of the MAI-plus-noise while keeping longer tails, the kurtosis matching (KM) method combined with the method of moments estimation (MME) is proposed for the parameter estimation for time-hopping UWB multiple access communications in AWGN channels. The GNL based UWB receiver using the KM approach outperforms the conventional matched filter receiver, the soft-limiting receiver, the Gaussian-Laplace mixture receiver, and the MME-based GNL receiver in high SNR ranges.

Keywords: generalized normal-Laplace (GNL) distribution, time-hopping (TH) ultra-wideband (UWB), multiple access interference (MAI), kurtosis matching, soft-limiting, Gaussian-Laplace mixture
Classification: Microwave and millimeter wave devices, circuits, and systems

References

[1] B. Hu and N. C. Beaulieu, "Accurate Evaluation of Multiple-Access Performance in TH-PPM and TH-BPSK UWB Systems," *IEEE Trans. Commun.*, vol. 52, no. 10, pp. 1758–1766, Oct. 2004.
[2] N. C. Beaulieu and D. J. Young, "Designing Time-Hopping Ultrawide Bandwidth Receivers for Multiuser Interference Environments," *Proc. IEEE*, vol. 97, no. 2, pp. 255–284, Feb. 2009.
[3] W. J. Reed, "The Normal-Laplace Distribution and Its Relatives," *In: Balakrishnan, N., et al. (Eds.), Advances in Distribution Theory, Order Statistics, and Inference*, Birkhäuser, Boston, pp. 61–74, 2006.
[4] S. Kim, "Detectors for Signals in Generalised Normal-Laplace Distributed Noise," *IET Electronics Letters*, vol. 46, no. 10, pp. 683–684, May 2010.
[5] S. Kim, "Reliability of Generalized Normal Laplacian Distribution Model in TH-BPSK UWB Systems," *IEICE Trans. Fundamentals*, vol. E94-A, no. 8, pp. 1772–1775, Aug. 2011.
[6] J. An and S. Kim, "A Novel Receiving Technique for Multi-User Interference in TH-UWB System," *Proc. IEEK Summer Conference*, pp. 15–17,

DOI: 10.1587/elex.8.1505
Received August 03, 2011
Accepted August 29, 2011
Published September 25, 2011

ELectronics EXpress

June 2011.
[7] S. M. Kay, *Fundamentals of Statistical Signal Processing. Volume II: Detection Theory*. Upper Saddle River, NJ: Prentice Hall, 1998.

1 Introduction

Since the performance of time-hopping (TH) ultra-wideband (UWB) systems is substantially degraded by multiple access interference (MAI) [1], it is important to design improved UWB receivers which can have good performance in multiple access communication environments. To develop enhanced multi-user UWB receivers, various probability distribution functions for better modeling the MAI in the UWB systems have been considered [2]. Recently, a normal-Laplace (NL) distribution function has been generalized to a new probability distribution case, which is called a generalized normal-Laplace (GNL) distribution [3, 4]. In [5], the GNL distribution has been considered for analyzing the performance of the conventional single-user correlation receiver in multi-user UWB systems. In this letter, an improved multi-user UWB receiver based on the GNL distribution is introduced for TH UWB signal detection. The GNL distribution is considered to reflect the heavy-tailed and impulsive nature of the MAI-plus-noise in TH UWB systems. The method of moments estimation (MME) is employed to estimate five parameters of the GNL distribution. In order to improve the performance of the GNL receiver for high signal to noise ratio (SNR) values, the kurtosis matching (KM) method is used together with the MME approach. This KM-based MME algorithm makes the probability density function (PDF) of the GNL distribution to more accurately represent the impulsive feature of the MAI-plus-noise while keeping longer tails. It is shown that the GNL UWB receiver employing the KM-based MME (called GNL-KM-MME UWB receiver) outperforms the conventional matched filter (CMF) receiver [2], the soft-limiting (SL) receiver [2], the Gaussian-Laplacian mixture (GLM) receiver [2], and the MME-based GNL UWB receiver [6] (called GNL-MME UWB receiver).

2 System model

A TH binary phase-shift keying (BPSK) UWB system is considered. Assuming N_u users are transmitting asynchronously on an AWGN channel, the received signal is written as [1]

$$r(t) = \sqrt{\frac{E_b}{N_s}} \sum_{k=1}^{N_u} a_k d_0^{(k)} \sum_{j=0}^{N_s-1} p(t - jT_f - c_j^{(k)} T_c - \tau_k) + n(t) \quad (1)$$

where $p(t)$ is the UWB pulse with unit energy and pulse width T_p. The second derivative of the Gaussian pulse is employed as the UWB pulse with the pulse shaping factor τ_p. E_b is the average bit energy common to all signals. N_s is the repetition code length. T_f is the average pulse repetition

DOI: 10.1587/elex.8.1505
Received August 03, 2011
Accepted August 29, 2011
Published September 25, 2011

ELectronics EXpress

interval, and thus, the bit duration is given by $T_b = N_s T_f$. The sequence $\{c_j^{(k)}\}$ is the TH code sequence for the kth user, which takes an integer in the range $0 \leq c_j^{(k)} < N_h$, where N_h is the number of hops. T_c is the chip duration of TH code and satisfies $N_h T_c \leq T_f$. $d_0^{(k)} \in \{\pm 1\}$ is the 0th binary data bit transmitted by the kth user with equal probabilities. $\{a_k\}_{k=1}^{N_u}$ represent the channel gains for all transmitted signals, and τ_k is the delay of the kth user and are uniformly distributed on a bit duration $[0, T_b)$. $n(t)$ is the AWGN with two-sided power spectral density $N_0/2$. Assume that the transmitted signal of the first user and $d_0^{(1)}$, respectively, are the reference signal and desired symbol. Without loss of generality, it is further assumed that $\tau_1 = 0$ and $c_j^{(1)} = 0$ for all j.

The time shift difference between different users can be modeled as $\tau_k - \tau_1 = m_k T_f + f_k$ [1] where m_k is the value of the time difference $\tau_k - \tau_1$ rounded to the nearest frame time, and f_k is the fractional part uniformly distributed on $[-T_f/2, T_f/2)$. Assuming perfect synchronization with the reference signal and $N_h T_c < T_f/2 - 2T_p$, the decision statistic of the CMF receiver is given by [1]

$$r = \sum_{m=0}^{N_s-1} r_m = \sum_{m=0}^{N_s-1} (S_m + I_m + n_m) = \sum_{m=0}^{N_s-1} (S_m + \Lambda_m) \tag{2}$$

where r_m is the chip correlator output in the mth frame, and $S_m = a_1 \sqrt{E_b/N_s} d_0^{(1)}$ is the desired signal component on the mth frame. The random variable $\Lambda_m = I_m + n_m$ is the total disturbance in the mth frame, where I_m is the MAI from the $N_u - 1$ interfering signals and n_m is the AWGN component which is Gaussian distributed with zero mean and variance $N_0/2$.

3 GNL receiver

The detection scheme for signals in GNL distributed noise consists of a nonlinearity function followed by an accumulator whose output is compared with the threshold 0. From Neyman-Pearson (NP) lemma, the GNL detector is given by the log-likelihood ratio test [6]

$$L_{NP}(\mathbf{r}) = \sum_{m=0}^{N_s-1} v_{np}(r_m) \begin{cases} > 0 \\ < 0 \end{cases} \tag{3}$$

where $\mathbf{r} = [r_0 \ r_1 \cdots r_{N_s-1}]$ and the nonlinearity function $v_{np}(r_m)$ is defined by

$$v_{np}(r_m) = \ln \left[\frac{f(r_m - |S_m|)}{f(r_m + |S_m|)} \right] \tag{4}$$

and $f(\cdot)$ represents the PDF of the GNL distributed noise and is numerically obtained by an inverse Fourier transform of the characteristic function of the GNL distribution. An MME, which is computationally simple, is considered for parameter estimation of the GNL distribution parameters [5]. In the $GNL(\mu, \sigma^2, \alpha, \beta, \rho)$ distribution, μ is a location parameter and σ^2 is a scale parameter influencing on the spread of the GNL distribution. α and β are parameters determining upper and lower tail behavior, respectively. Here, the

DOI: 10.1587/elex.8.1505
Received August 03, 2011
Accepted August 29, 2011
Published September 25, 2011

IEICE Electronics Express, Vol.8, No.18, 1505–1510

case of symmetric distribution ($\alpha = \beta$) is considered. When α goes to infinity, the upper tail of GNL PDF corresponds to that of a normal distribution. If the value of α gets smaller, the upper tail of the GNL distribution becomes fatter. ρ is a shape parameter which also controls the tail shape. As the value of ρ decreases, the GNL distribution has a sharper peak, thinner flanks and longer tails.

4 Improved GNL receiver

In Fig. 1, the distribution of the MAI-plus-noise is generated by simulation and are compared with PDF of the MAI-plus-noise obtained by the GNL approximation. The set of parameters of the TH-BPSK UWB systems is given by the followings: time normalization factor $\tau_p = 0.2877$ ns, impulse time width $T_p \approx 0.7$ ns, frame time $T_f = 50$ ns, chip time $T_c = 0.9$ ns, number of chips per frame $N_h = 8$, periodicity of TH code $N_p = 8$, and repetition code length $N_s = 4$. The single-user synchronous SNR and signal to interference ratio (SIR) at the correlator output, respectively, are defined as $SNR = E_b/N_0$ and $SIR = a_1^2 E_b N_s/\text{var}(I)$ where $I = \sum_{m=0}^{N_s-1} I_m$. Fig. 1 shows the PDF of the MAI-plus-noise component in TH-BPSK systems for 3 ($N_u = 4$) equal power interfering users with $SNR = 25$ dB and $SIR = 10$ dB. It also contains the PDF based on GNL approximation for comparison in which the GNL parameters are estimated by an MME approach. It is called a GNL-MME PDF. The MME estimates of μ, σ^2, α, β, ρ could be sometimes negative. In this case, the absolute values of MME estimates $\hat{\mu}$, $\hat{\sigma}^2$, $\hat{\alpha}$, $\hat{\beta}$, $\hat{\rho}$ have been used for the numerical simulations. As shown in Fig. 1 as an example with $SNR = 25$ dB and 3 interferers, the GNL-MME PDF sometimes differs from the actual distribution in the high SNR values where it

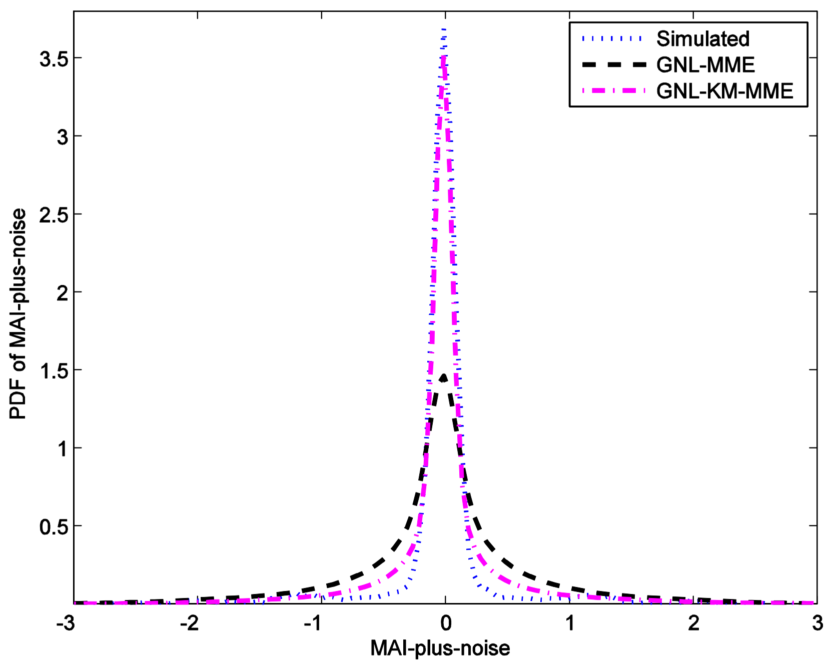

Fig. 1. A comparison of the PDFs of the MAI-plus-noise with GNL distribution model for 3 interferers

DOI: 10.1587/elex.8.1505
Received August 03, 2011
Accepted August 29, 2011
Published September 25, 2011

IEICE Electronics Express, Vol.8, No.18, 1505–1510

does not represent accurately the impulsive nature at small amplitude levels of the MAI-plus-noise and the heavy tail at the high amplitude levels of the MAI-plus-noise.

In order to more precisely obtain the impulsive PDF with longer tails in the range of high SNRs, the MME approach for GNL parameter estimation needs to be modified. In the GNL distribution, the decrease of the shape parameter ρ makes the PDF curve to have a sharper peak, thinner flanks, and longer and heavier tails. The heaviness of the PDF's tail can be typically measured by its excess kurtosis [7]. Thus if the MME parameter $\hat{\rho}$ with other MME estimates unchanged is adjusted according to actual kurtosis values of the MAI-plus-noise, the modified GNL-MME PDF could get a more impulsive peak and heavier tails. The actual kurtosis value [7] and the coefficient of kurtosis of the GNL distribution [3], respectively, are given by

$$K_{act} = \frac{E[I^4]}{[E[I^2]]^2} - 3 \tag{5}$$

$$K_{GNL} = \frac{6(\alpha^4 + \beta^4)}{\rho(\sigma^2\alpha^2\beta^2 + \alpha^2 + \beta^2)^2} \tag{6}$$

Here, to get the GNL PDF with a more impulsive peak and heavier tails according to actual kurtosis values K_{act}, the updated shape parameter $\hat{\rho}_{KM}$ can be determined by matching K_{act} and K_{GNL}. Thus, using the GNL estimates, $\hat{\mu}$, $\hat{\sigma}^2$, $\hat{\alpha}$, and $\hat{\beta}$, the $\hat{\rho}_{KM}$ is given by

$$\hat{\rho}_{KM} = \frac{6(\hat{\alpha}^4 + \hat{\beta}^4)}{K_{act}(\hat{\sigma}^2\hat{\alpha}^2\hat{\beta}^2 + \hat{\alpha}^2 + \hat{\beta}^2)^2} \tag{7}$$

Here, the GNL-MME PDF based on the KM method is called a GNL-KM-MME PDF. It is observed in Fig. 1 that the GNL-KM-MME PDF represents

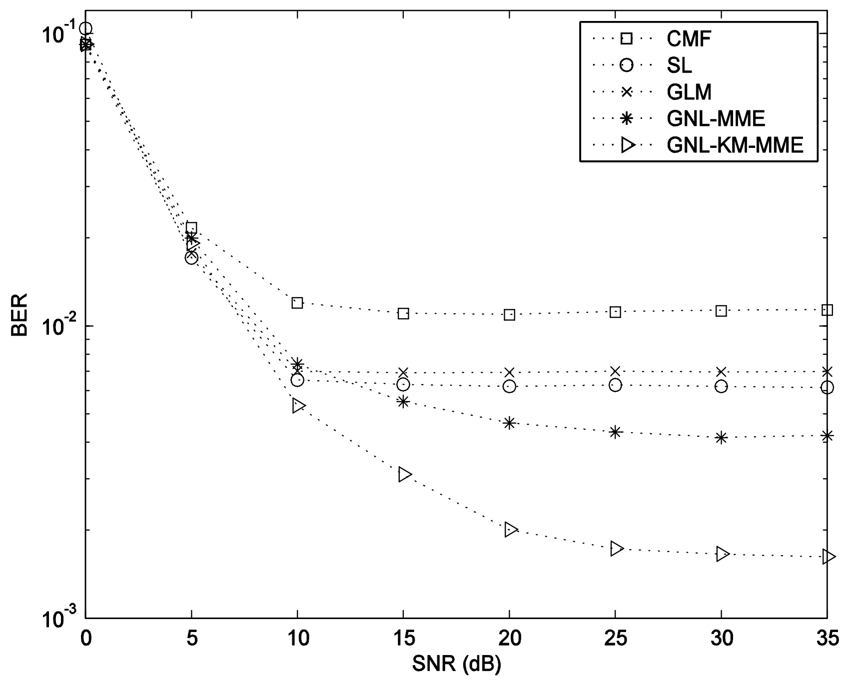

Fig. 2. Average BERs versus SNR for 3 interferers

© IEICE 2011
DOI: 10.1587/elex.8.1505
Received August 03, 2011
Accepted August 29, 2011
Published September 25, 2011

IEICE Electronics Express, Vol.8, No.18, 1505–1510

the simulated one better than the GNL-MME PDF in a given multiuser scenario.

Fig. 2 shows the BER performance of the CMF, SL, GLM, GNL-MME, and GNL-KM-MME UWB receivers in the presence of MAI with 3 equal power interferers with $SIR = 10\,\text{dB}$, where the values of the system parameters are the same as those used in Fig. 1. The GNL-MME UWB receiver outperforms the CMF, SL, and GLM UWB receivers in the range of more than $SNR = 10\,\text{dB}$. The GNL-KM-MME UWB receiver has better BER performance than the others for large SNR ranges.

5 Conclusion

This letter has proposed an improved multi-user receiver based on GNL distribution model in multi-user TH UWB systems. The GNL-MME UWB receiver provides better performance than the CMF, SL, and GLM UWB receivers in the range of high SNRs. Moreover, the KM method has been employed to modify one of MME estimates of GNL parameters, $\hat{\rho}$, and thus makes the GNL PDF curve to more accurately represent the impulsive feature of the MAI-plus-noise for 3 interferers in the high SNRs. Hence, the GNL-MME UWB receiver has been more improved by the KM approach.

Acknowledgments

This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education, Science and Technology (2011-0005368).

DOI: 10.1587/elex.8.1505
Received August 03, 2011
Accepted August 29, 2011
Published September 25, 2011