Spectrum-Based SNR Estimator for Analog and Digital Bandpass Signals

H. Kashefi , S. Karimkeshteh and H. Khoshbin Ghomash
Electrical Engineering Department, Ferdowsi University of Mashhad,
Mashhad, Iran
E-mail: {ha_ka301, sahar.karimkeshteh}@stu-mail.um.ac.ir

Abstract—**A signal-to-noise ratio (SNR) estimation algorithm for analog and digital communication systems is presented, which is simple and practical. We modified the existing spectrum-based SNR estimator for analog modulation and applied it to analog and digital modulated signals over the real and complex Additive White Gaussian Noise (AWGN) channel. This is a non-data-aided estimator which can be applied to any modulated signals, which is a feature that is not common in the existing estimators. The performance of the new SNR estimator is investigated by computer simulation under different analog and digital bandpass modulated signals.**

Keywords- Signal-to-noise-ratio, digital modulation, Non-data-aided (NDA) estimator.

I. Introduction

Signal-to-noise ratio (SNR) is an important measure of the channel quality which is widely used in communication systems. Many techniques and their applications are based on the knowledge of SNR to reach a desired performance, such as power control, adaptive modulation and coding, BER estimation and blind signal classification.

Based on the amount of knowledge of the transmitted signal, SNR estimators can be classified as data-aided (DA) estimators and non-data-aided (NDA) or blind estimators. DA estimators rely on the knowledge of transmitted data while in the NDA estimators SNR estimation comes only from unknown information-bearing part of the received signal. NDA estimators do not invade on the throughput of the channel because setting a training sequence in the data stream is not required, therefore they are so practical.

SNR estimation methods for digital and analog modulated signals over Additive White Gaussian Noise (AWGN) channel have been published in several literatures which are listed here as reference. In [1]-[4], the well-known M2M4 estimator over AWGN channel is utilized based on the second and forth moments of the received signal and it's applicable for M-ary phase shift keying (MPSK) signals. The Split-Symbol Moment Estimator (SSME) provided in [5] and [6] is designed to estimate symbol signal-to-noise ratio and can be applied to binary PSK modulated signals in real AWGN channel. Maximum-Likelihood (ML) SNR estimator which converts the problem of SNR estimation into the ML approximation of a signal's amplitude is introduced in [7] and [8] for BPSK signals and in [1] for M-ary PSK signals over real and complex AWGN channel. Squared Signal-to-Noise Variance (SNV) estimator is introduced in [9] for BPSK signals in real AWGN channel and it is derived for M-ary PSK signals in real and complex AWGN channel in [1]. Signal-to-Variation Ratio (SVR) Estimator described in [10] for multipath fading channel and this estimator is sketched in [1] to operate on any M-ary PSK-modulated signals over real and complex AWGN channel. From the above induction we can find that the mentioned estimators rely on the modulation type of received signal and also assume that the received signal is a baseband signal; this assumption is not always available. In [11], an Eigenvalue Decomposition (ED) estimator is proposed which does not need knowledge of modulation type of the received signal and can be applied to bandpass modulated signals but it has computational complexity. In [12], a SNR estimator using the iterative subspace tracking algorithm is presented which compared to the ED-based method has a lower computational complexity.

In [13], there are some methods to estimate SNR for analog modulated signals over AWGN channel and a Spectrum-based SNR estimator which uses Fast Fourier Transform (FFT) of received signal. Since this estimator does not assume that the amplitude of received signal has to be constant, it can be applied to Amplitude Modulation (AM), Double Sideband Modulation (DSB), Single Sideband Modulation (SSB) schemes moreover Phase Modulation (PM) and Frequency Modulation (FM). We modified it for analog modulation and extended this algorithm to digital bandpass modulated signals, which is simple and practicable for more complicated constellations other than BPSK constellation.

The remaining paper is organized as follows: Section II provides an expression of SNR estimation Problem and the system model. In Section III a blind spectrum-based SNR estimator is presented. The performance analysis is described in Section IV. Simulation results are presented in Section V. Section VI concludes the paper.

II. System Model

In this section, we consider a communication system over an Additive White Gaussian Noise (AWGN) channel. Channel can be real-valued or complex-valued. The received signal can be expressed as

978-1-4673-2073-3/12/$31.00 ©2012 IEEE

$$r_k = \sqrt{S}x_k + n_k, k = 1,2,...,L \quad (1)$$

where x_k denotes the analog or digital bandpass modulated signal, which could be any modulated signal, at the carrier frequency of F_c. The sampling frequency is F_s which is larger than twice of carrier frequency. Also S is a signal power scale factor and L denotes the length of signal for SNR estimation. n_k is an AWGN sample having zero-mean and variance of σ^2.

We want to estimate SNR as signal power to noise power ratio, which is defined as

$$\rho = 10\log_{10}(\frac{S}{N}), dB \quad (2)$$

where N is a noise power.

III. Spectrum-based NDA Estimimator

In this section we introduce the spectrum-based estimator and its development to digital modulation signals. This estimator uses envelop of Fourier spectrum of a received signal which is corrupted by the noise for finding the signal power and the noise power. Since this estimator does not rely on the parameters of received signals, therefor it can be applied to a wide range of analog and digital bandpass signals.

Estimator uses the following steps:

- Compute L -point Fast Fourier Transform (FFT) of received signal r_k, which L is the length of the received signal r_k. Denote the FFT spectrum as F(n);
- Calculate envelop of F(n) and nominate it as E(n);
- Compute total signal-plus-noise power using the Parseval's theorem based on Fourier spectrum and denote it as S_{x+n};
- Based on F(n), an approximate range of frequencies occupied by the signal plus noise can be located, the remaining portion of Fourier spectrum assumed to be the noise only;
- For finding the noise power, calculate the mean of E(n) inside the noise portion and denote it as σ_n. Then estimate the noise power by:

  $$N = (\sigma_n k)^2 L \quad (3)$$

  where k is constant.
- Estimate signal power by:

  $$S = S_{x+n} - N \quad (4)$$

- Finally compute the estimated SNR by (2)

IV. Simulation Results

For the sake of analyzing the performance of our estimator for digital modulated signals and in order to provide the comparison of two estimators for analog modulated signals, we used the bias and the standard deviation (STD) which are defined as

$$Bias\{\hat{\rho}\} = \frac{1}{M_t}\sum_{t=1}^{M_t}(\hat{\rho}_t - \rho), dB \quad (5)$$

$$STD\{\hat{\rho}\} = \left(\frac{1}{M_t}\sum_{t=1}^{M_t}(\hat{\rho}_t - \bar{\rho})^2\right)^2, dB \quad (6)$$

where $\bar{\rho} = \frac{1}{M_t}\sum_{t=1}^{M_t}\hat{\rho}_t$, $\hat{\rho}_t$ is an estimated SNR over the t^{th} trial, ρ is the true SNR and M_t is the number of trial which is 200 in our simulation.

First we take MPSK, MFSK, MQAM and MASK into consideration. For the sake of evaluating the performance of spectrum-based SNR estimator for digital bandpass signal, several simulations are done. The parameters of received signal are as follows. The carrier frequency is 3000Hz, the sampling frequency is 7500Hz and length of signal is 15000.

In the abovementioned algorithm for finding the σ_n, we can also calculate the mean of E(n) in the first short interval of noise portion (for example from 1 to L/100 of E(n)). If it is estimated that the carrier frequency is between 30% and 50% of the sampling frequency (which is common), we can calculate the mean of E(n) from 1 to L/6 of E(n), which decreases standard deviation. We used $k = 1.12$ for all analog and digital signals and SNRs. This value is chosen through the simulation.

Simulation is also done for analog modulated signals for PM, FM, AM, DSB and USSB signals. Results are shown in Figures 6 - 8. Finally we compare the spectrum-based estimator in [13] and our modified estimator.

Fig.1 illustrates the estimated mean of tested SNRs. we can see that the estimation mean is superposed with the true values. The results represent that the performance of this SNR estimator is independent from modulation schemes and their orders.

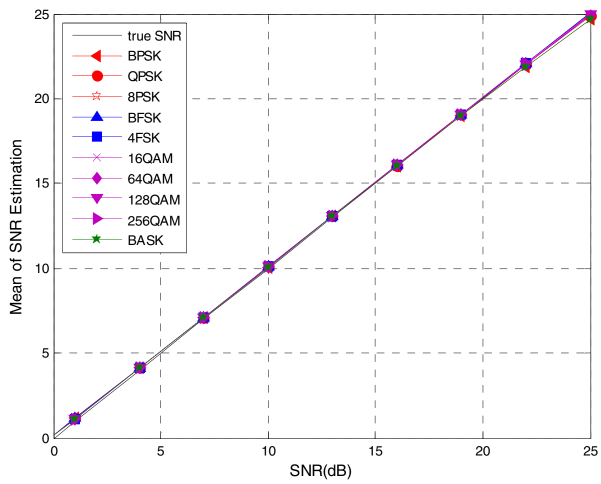

Figure 1. Mean of SNR Estimation vs. SNR

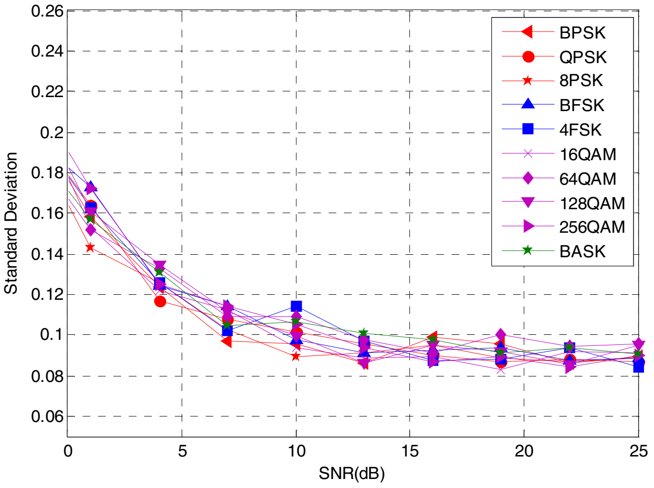

Figure 2. Standard deviation of SNR estimation vs. SNR

In Fig.2 we can see that the standard deviation (STD) of spectrum-based estimator decreases by increasing SNR.

Fig.3 shows that when SNR is high, the normalized bias decreases and the modulation types do not affect the bias.

To show the relationship between the accuracy of SNR estimation and the number of received signal, the mean of SNR estimation at the different signal lengths for a constant SNR is shown in Fig.4. Results for some modulated signals such as 8PSK, 16QAM and 128QAM show that the estimated mean is a little better when the signal length is increasing.

Fig.5 shows the STD of four modulated signals according to the signal length when SNR is 15dB. As it can be seen, the STD reduces quickly by increasing the length of signal.

Fig.6 illustrates the mean of SNR estimation for analog modulated signals over real AWGN channel. As it has been shown, our estimator tracks the true SNR from -5dB to 15dB. At high SNRs, the performance degrades for FM, DSB and USSB signals.

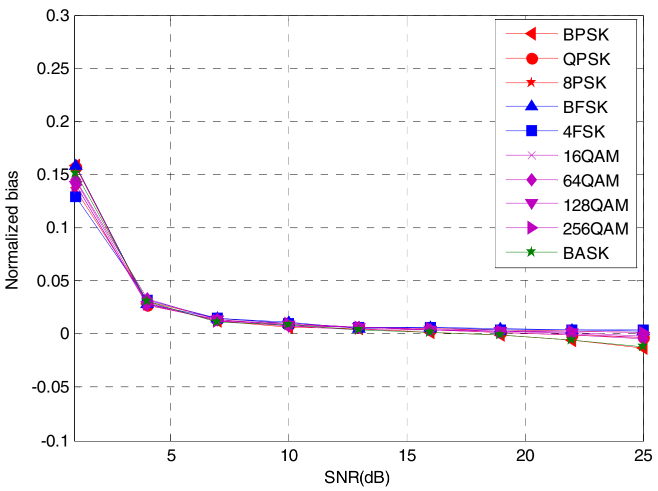

Figure 3. Normalized bias of SNR Estimation vs. SNR

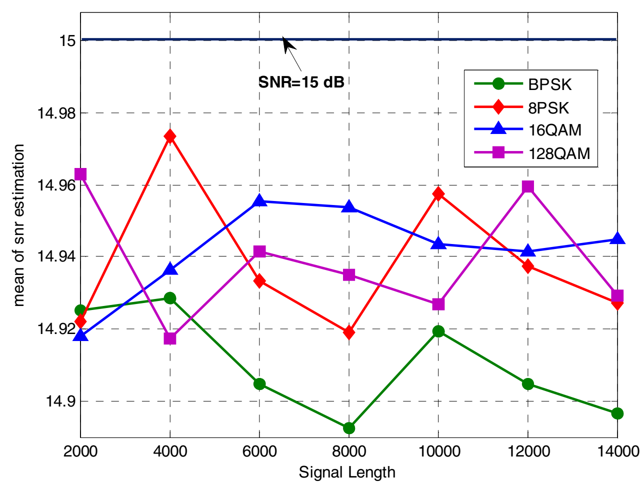

Figure 4. Mean of SNR Estimation vs. signal length

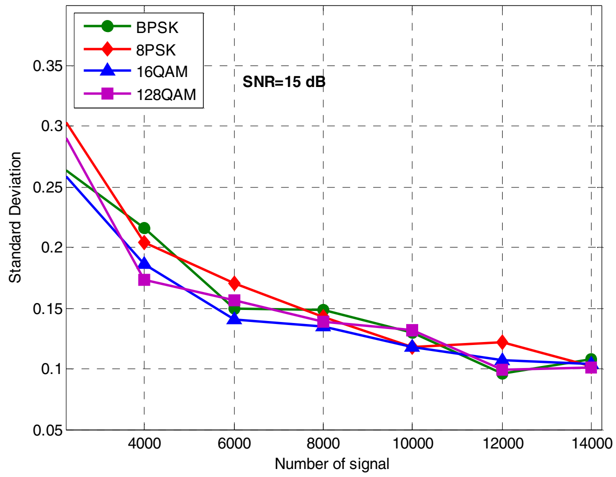

Figure 5. Standard Deviation of SNR Estimation vs. Signal Length

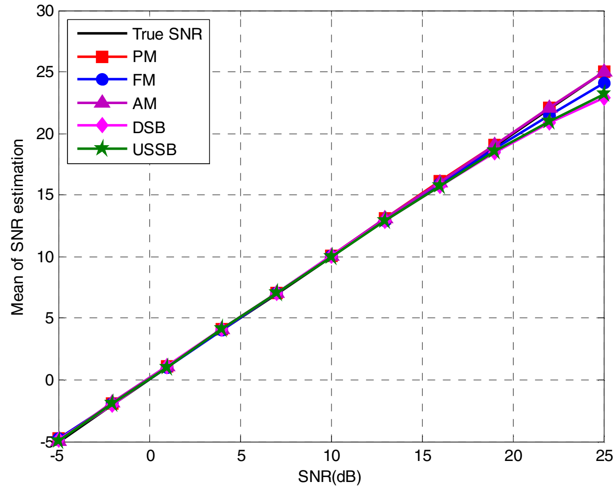

Figure 6. Mean of SNR estimation vs. true SNR

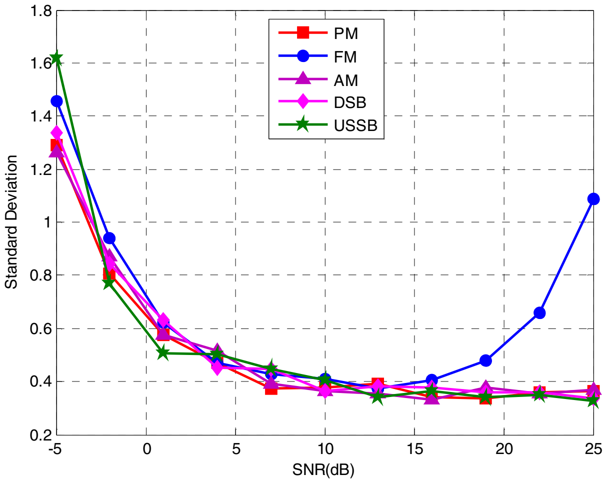

Figure 7. Standard deviation of SNR estimation vs. true SNR

The standard deviation of estimation for analog modulated signals is shown in Fig.7. We can see that the STD reduces by increasing the SNR and at high SNRs, STD is below the 0.4.

We plotted the bias of estimator for analog modulated signals in Fig.8. As it can be seen, the bias of FM, DSB and USSB signals increase by increasing the SNR.

Fig.9 compares the bias of PM and USSB signals for the estimator in [13] and modified estimator. As it can be seen our estimator has a better performance at all range of SNRs.

For comparing the standard deviation of estimator in [13] and our modified estimator, Fig.10 is plotted. We can see that the STD of our estimator is lower than the spectrum-based estimator in [13] from 4dB to 25dB.

We also tried our simulations with different sampling rates and carrier frequencies in real and complex AWGN. The experiments show that the performance of the spectrum-based estimator for digital and analog signals is nearly independent of those factors.

V. Conclusion

A Spectrum-based NDA estimator is modified and applied to analog and digital bandpass modulated signals in real and complex Additive White Gaussian Noise. Computer simulations for commonly analog and digital modulated signals show that this estimator is effective in a wide range of SNRs and it does not rely on the modulation scheme, carrier frequency and sampling rate of the received signal. Complexity is a factor to be considered. Spectrum-based estimator has low computational complexity and can be used in real time SNR estimation. Also since the estimator for digital modulated signals could be applied to high order modulated signals, it can be used in high rate communications.

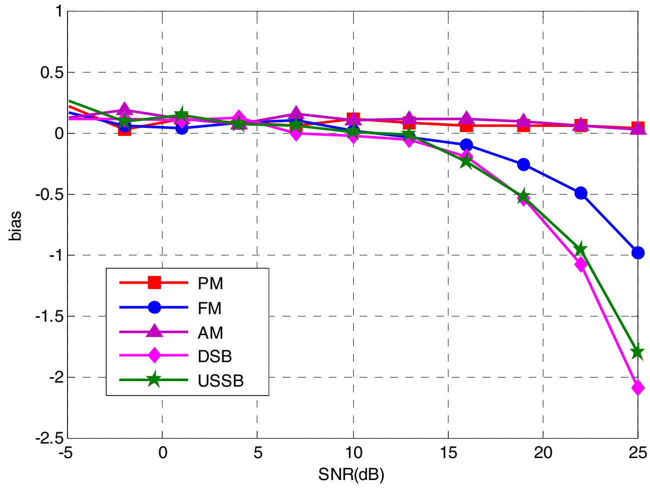

Figure 8. Bias of SNR estimation vs. true SNR

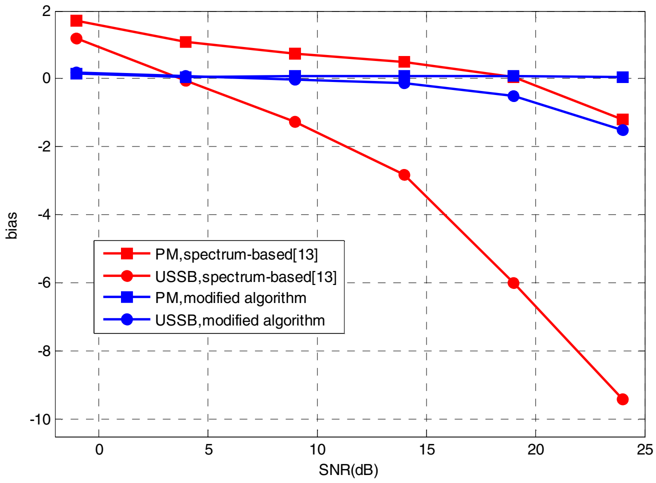

Figure 9. Bias of SNR estimation vs. true SNR

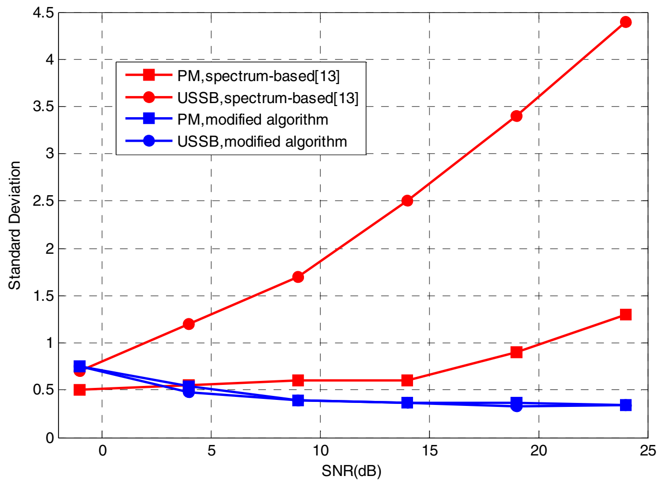

Figure 10. Standard deviation of SNR estimation vs. true SNR

ACKNOWLEDGMENT

The authors would like to thank Shahid Aghasi-zade Research Center for their cooperation and the authors would also like to thank M. Abbasi Jannat-abad for sharing his knowledge generously.

REFERENCES

[1] D. R. Pauluzzi and N. C. Beaulieu, "A comparison of SNR estimation techniques for the AWGN channel," Communications, IEEE Trans. Communications. vol. 48, pp.1681-1681, 2000.

[2] T. R. Benedict and T. T. Soong, "The joint estimation of signal and noise from the sum envelope," IEEE Trans. Inform. Theory, vol. IT-13, pp. 447–454, July 1967.

[3] R. Matzner, "An SNR estimation algorithm for complex baseband signals using higher order statistics," Facta Universitatis (Nis), no. 6, pp. 41–52, 1993.

[4] R. Matzner and F. Engleberger, "An SNR estimation algorithm using fourth-order moments," in *Proc. IEEE Int*. Symp. Information Theory, Trondheim, Norway, June 1994, p. 119.

[5] B. Shah and S. Hinedi, "The split symbol moments SNR estimator in narrow-band channels," IEEE Trans. Aerospace. Electron.Syst. Vol. AES-26, pp. 737-747, Sept. 1990.

[6] M. K. Simon, A. Mileant, "SNR Estimation for the Baseband Assembly," Telecommunications and Data Acquisition Progress Report 42-85**,** Jet propulsion Laboratory, Pasadena, CA, May 15, 1986, 118-126**.**

[7] R. B. Kerr, "On signal and noise level estimation in a coherent PCM channel," IEEE Transactions on Aerospace. Electron. Syst., vol. AES-2, pp. 450–454, July 1966.

[8] R. M. Gagliardi and C. M. Thomas, "PCM data reliability monitoring through estimation of signal-to-noise ratio," IEEE Trans. on Communication, vol. COM-16, pp. 479–486, June 1968.

[9] C. E. Gilchriest, "Signal-to-noise monitoring," JPL Space Programs Summary, vol. IV, no. 37-27, pp. 169–184, June 1966.

[10] A. L. Brandão, L. B. Lopes, and D. C. McLernon, "In-service monitoring of multipath delay and cochannel interference for indoor mobile communication systems," Proc. IEEE Int. Conf. Communications, vol. 3, pp. 1458–1462, May 1994.

[11] D. Sui and L. Ge, "A Blind SNR Estimator for Digital Bandpass Signals," in Proc. 6th ITS conf. pp. 1334-1337, 2006.

[12] SUI Dan, GE Lindong, Wang Qing, Hui Zhang, "A Blind SNR Estimator for Based on Iterative Subspace Tracking Algorithm for Digital Modulated Signals", Proceedings of 2006 IEEE information Theory Workshop (ITW), 2006.

[13] H. Xiao, Y. Q. Shi, W. Su and J. Kosinski, "An Investigation of Non-Data-Aided SNR Estimation Techniques for Analog Modulation Signals," IEEE Sarnoff symposium, 2010.