A NOVEL FRONT-END NOISE POWER AND SNR ESTIMATION USING WAVELET-PACKETS IN OFDM SYSTEMS

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Keywords: SNR, Noise power estimation, Adaptive modulation, OFDM.

Abstract: In this paper, a noise power estimator based on one OFDM preamble is proposed. The estimator, unlike others, performs noise power estimation at the front-end of the receiver. The proposed estimator takes into consideration the different noise power levels over the OFDM sub-carriers. The OFDM band is divided into several sub-bands using wavelet packet and noise in each sub-band is considered white. The second-order statistics of the transmitted OFDM preamble are calculated in each sub-band and the noise power is estimated. The proposed estimator is compared with Reddy's estimator for colored noise in terms of mean squared error (MSE).

1 INTRODUCTION

Signal-to-noise ratio (SNR) is defined as the ratio of the desired signal power to the noise power. Noise variance, and hence SNR estimates of the received signal, are very important parameters for quality control in communication systems (Xiaodong et al., 2005). The search for a good SNR estimation technique is motivated by the fact that various algorithms require knowledge of the SNR for optimal performance. For instance, in OFDM systems, SNR estimation is used for power control, adaptive coding and modulation, turbo decoding etc.

SNR estimation indicates the reliability of the link between the transmitter and receiver. In adaptive system, SNR estimation is commonly used for measuring the quality of the channel and accordingly for changing the system parameters. For example, if the measured channel quality is low, the transmitter may add some redundancy or complexity to the information bits (more powerful coding), or reduce the modulation level (better Euclidean distance), or increase the spreading rate (longer spreading code) for lower data rate transmission. Therefore, instead of implementing fixed information rate for all levels of channel quality, variable rates of information transfer can be used to maximize system resource utilization with high quality of user experience (Reddy and Arslan, 2003).

Many SNR estimation algorithms have been suggested in the last ten years (Kamel and Joeti, 2006), (Bournard, 2003), (Pauluzzi and Norman, 2000) and many have been successfully implemented in OFDM systems at the back-end of receiver using the system pilot symbols. The essential requirement for an SNR estimator in OFDM system is of low computational load. This is in order to minimize hardware complexity as well as the computational time.

In contrast to other SNR estimators, the proposed technique operates on data collected at the front-end of the receiver, imposing no restriction on ISI. This will improve the SNR estimates in severe ISI channels and also help extending the implementation of SNR estimators towards systems that require SNR estimates at the input of the receiver. One such application is antenna diversity combining, where at least two antenna signal paths are communicably connected to a receiver. The combiner can use the SNR estimates obtained from each antenna signal to respectively weight them and thereby generate a combined output signal.

In many SNR estimation techniques, noise is assumed to be uncorrelated or white. But, in wireless communication systems, where noise is mainly caused by a strong interferer, noise is colored in nature.

In this paper, a front-end noise power and SNR estimator for the colored noise in OFDM system is

Shahid Manzoor R., Jeoti V., Kamel N. and Asif M. (2008).
A NOVEL FRONT-END NOISE POWER AND SNR ESTIMATION USING WAVELET-PACKETS IN OFDM SYSTEMS.
In *Proceedings of the International Conference on Wireless Information Networks and Systems*, pages 140-144
DOI: 10.5220/0002023301400144

proposed. The algorithm is based on the two identical halves property of time synchronization preamble used in some OFDM systems. The OFDM band is divided into several sub-bands using wavelet packet and noise in each sub-band is considered white. The second-order statistics of the transmitted OFDM preamble are calculated in each sub-band and the power noise is estimated. Therefore, the proposed approach estimates both local (within smaller sets of subcarriers) and global (over all sub-carriers) SNR values. The short term local estimates calculate the noise power variation across OFDM sub-carriers. When the noise is white, the proposed algorithm works as well as the conventional noise power estimation schemes, showing the generality of the proposed method.

The remainder of the paper is organized as follows. In Section 2, the proposed technique is presented. Section 3 provides the overview of Reddy's estimator. Section 4 presents simulation results and discussion. Section 5 concludes the paper.

2 FRONT-END BASED NOISE POWER AND SNR ESTIMATION TECHNIQUE IN OFDM SYSTEM

The methodology of the estimator is depicted in the Fig.1. The synchronization preamble of an OFDM system - the preamble which has two identical halves property, is obtained by loading constellation (QPSK) points with a PN sequence (P_{seq}) at even sub-carriers using eq.1 (IEEE, 2004).

$$P_{even}(k)=\begin{cases}\sqrt{2}.P_{seq}(m) & k=2m\\ 0 & k=2m+1\end{cases} \qquad m=1,2,..N/2 \qquad (1)$$

where the factor of $\sqrt{2}$ is related to the 3 dB extra boost to preamble as compared to data and $'k'$ shows the sub-carriers index. This OFDM training/synchronization data of length 'N_{OFDM}' is sent from the transmitter (T_x). Inverse Fourier transform (IFFT) of transmitted OFDM data is performed to convert it into time domain. To avoid intersymbol interference (ISI) cyclic prefix (*CP*) is added as shown in Fig 2, so that the total length of OFDM data becomes $L_{total}=N_{OFDM}+CP$.

After adding cyclic prefix, OFDM data is divided into 2^n sub-bands using wavelet packets where '*n*' shows the number of levels. The length of each sub-band is $L_{sub}=N_{sub}+CP_{sub}$, where $Nsub= N_{OFDM}/2^n$ and $CP_{sub} = CP/2^n$. It inherits the two identical halves property of synchronization preamble. The noise in each sub-band is considered white as shown in Fig.3. The system's parameters and the structure of wavelet packet used for the simulations are given in Table1.

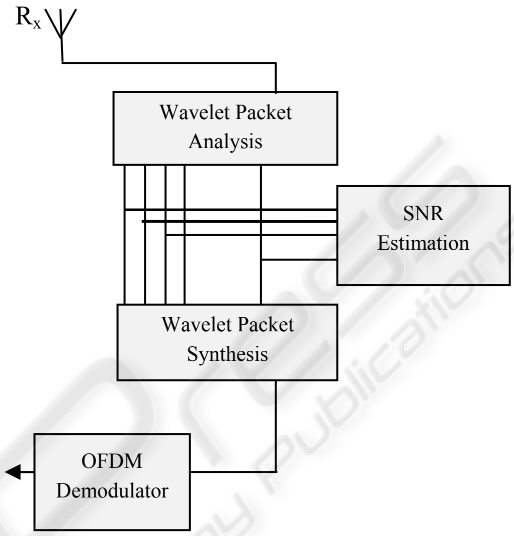

Figure 1: Methodology of proposed technique.

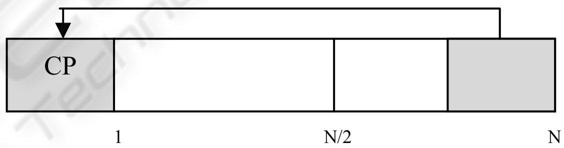

Figure 2: OFDM training symbol with cyclic prefix.

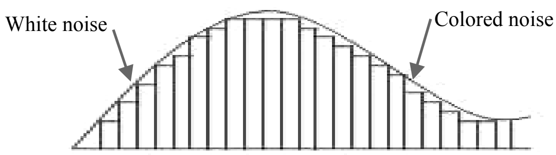

Figure 3: The spectrum of colored noise with approximate white noise over the sub-bands.

2.1 Signal Power and Noise Power Estimation

The autocorrelation function of the received signal at the front-end of receiver in each sub-band, $r_{xx}(m)$ has the following relationship to the autocorrelation of the transmitted sub-band signal, $r_{ss}(m)$ and the noise, $r_{nn}(m)$:

$$r_{xx}(m) = r_{ss}(m) + r_{nn}(m) \qquad (2)$$

The noise in channel is modeled as additive white Gaussian noise, thus its autocorrelation function can be expressed as

$$r_{nn}(m) = \sigma^2 \delta(m) \qquad (3)$$

where $\delta(m)$ is the discreet delta sequence and σ^2 is the power of noise in the subband.

A study of the OFDM signal shows that, as all the sub-carriers are present with equal power over the signal bandwidth, the power spectrum of an OFDM signal is nearly white and hence its autocorrelation is also given by

$$r_{ss}(m) = P_s \delta(m) \qquad (4)$$

Hence, at zero lag the autocorrelation contains both the signal power estimate and noise power estimate indistinguishable from each other.

However, because of the identical halves nature of the preamble the autocorrelation also has peaks where cyclic prefix matches with itself and also where one half matches with other half on both sides of the zero delay. The autocorrelation of the transmitted and received 5th sub-band signal at SNR = 7 dB are shown in Fig.4(a) and Fig.4(b), respectively. It is clear that the autocorrelation values apart from the zero-offset are unaffected by the AWGN, so one can find the signal and noise powers from the zero-lag autocorrelation value.

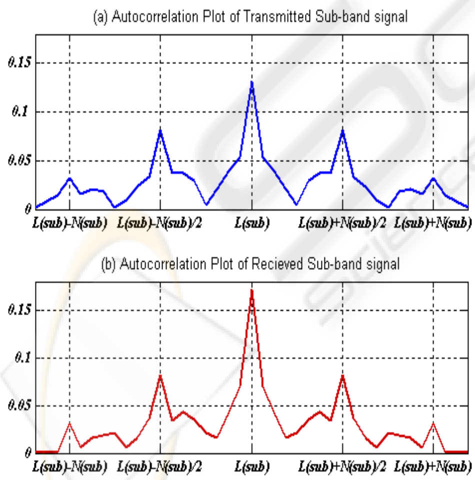

Figure 4: (a) Autocorrelation of transmitted signal. (b) Autocorrelation of received signal

Taking into consideration the autocorrelation values for L_{sub}-$N_{sub}/2$ and L_{sub}-N_{sub} lags or $L_{sub}+N_{sub}/2$ and $L_{sub}+N_{sub}$, signal power is given as

$$\hat{P}_{ss} = 2r_{xx}((L_{sub} - N_{sub}/2)) - r_{xx}(L_{sub} - N_{sub}) \qquad (5)$$

Or

$$\hat{P}_{ss} = 2r_{xx}((L_{sub} + N_{sub}/2)) - r_{xx}(L_{sub} + N_{sub}) \qquad (6)$$

Having obtained the power of signal in certain sub-band, noise power can be calculated as

$$\hat{\sigma}^2 = r_{xx}(L_{sub}) - \hat{P}_{ss} \qquad (7)$$

Finally we can find the SNR estimates in the sub-band by using equation (5 or 6) and equation (7).

$$S\hat{N}R = \frac{\hat{P}_{ss}}{\hat{\sigma}^2} \qquad (8)$$

where $S\hat{N}R$ is the estimated value for SNR.

3 REDDY'S SNR ESTIMATOR FOR COLORED NOISE

In this method channel estimation is performed in the first realization of the channel, using pilot symbols and this estimate is used to estimate the signal noise power. The suggested method can be used Additive white Gaussian noise (AWGN) channel and for color dominated channel, in which the noise power varies across the frequency spectrum.

The system model is described in the frequency domain, where a signal is transmitted to obtain the estimated channel frequency response after which the instantaneous noise power mean square is determined. The transmitted signal includes white noise which is added by the channel of unknown amplitude. This is modelled in the frequency domain by the equation:

$$Y_{m(k)} = X_{m(k)} H_{m(k)} + N_{m(k)} \qquad (9)$$

where

$X_{m(k)}$ = Transmitted signal

$Y_{m(k)}$ = Received signal

$N_{m(k)}$ = Channel white noise

The channel frequency response is estimated by transmitting preamble and performing division in the frequency domain of the received signal by the transmitted signal. When performing the division, the effect of noise is ignored. The pilot symbols are then used as the transmitted signal and the received signal in the pilot sub-carriers is used for the received signal and the estimated transfer function inserted in the equation to determine the noise power estimate. The noise power estimation is found by finding the difference between the noisy received signal and the noiseless signal.

$$E_{m(k)} = \left| Y_{m(k)} - \hat{X}_{m(k)} \hat{H}_{m(k)} \right|^2 \quad (10)$$

The difference between the actual channel frequency response and the estimated is the channel estimation error.

4 RESULTS AND DISCUSSION

The proposed technique is compared with Reddy's estimator for colored noise in OFDM system with parameters given in Table 1. Wavelet packet 4-level decomposition is performed with Daubechies-3 wavelet.

SNR is varied from 1 dB to 25 dB for each sub-band and in order to be statistically accurate, the mean-squared error (MSE) is derived for the estimated SNR from 2000 trials according to the following formula

$$MSE = \frac{1}{2000} \sum_{i=1}^{2000} (S\hat{N}R(i) - SNR)^2 \quad (11)$$

Bias is derived for the estimated SNR using eq.12.

$$Bias = \frac{1}{2000} \sum_{i=1}^{2000} (S\hat{N}R(i) - SNR) \quad (12)$$

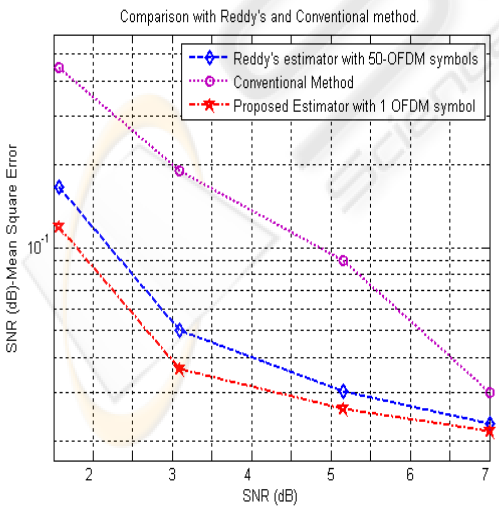

Figure 5: Mean-square-error performance of the proposed technique.

Fig.5 shows the MSE values for the proposed algorithm compared with Reddy as a function of SNR. Fig.6 and Fig.7 shows the actual SNR vs. estimated SNR comparison and Bias vs. Actual SNR over all OFDM symbol respectively.

Table1: Parameters for proposed technique.

Ifft size	256
Sampling Frequency = F_s	$20MHz.$
Sub Carrier Spacing= $\Delta f = F_s / Ifft$	1×10^5
Useful Symbol Time = $T_b = 1/\Delta f$	1×10^{-5}
CP Time = $T_g = G * T_b$ *where* $G = 1/4$	2.5×10^{-6}
OFDM Symbol Time = $T_s = T_b + T_g$	1.25×10^{-5}
$T_s = 5/4 * T_s$ *(Because ¼ CP makes the sampling faster by 5/4 times)*	1.56×10^{-5}
$T_{sub} = T_s / 16$	9.8×10^{-7}
Wavelet Packet Object Structure	
Wavelet Decomposition Command : wpdec *Size of initial data : [1 320]* *Order= 2 and Deptth=: 4* *Terminal nodes : [15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30]* --- *Wavelet Name : Daubechies (db3) ,* *Entropy Name : Shannon*	

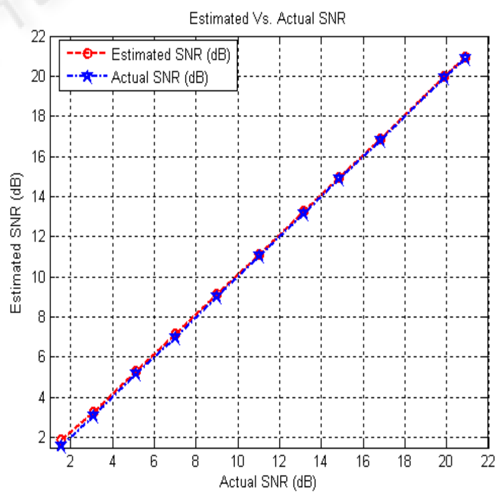

Figure 6: Actual SNR vs. Estimated SNR of colored noise.

The results show that the proposed estimator gives better performance in SNR estimation as compared to Reddy estimator. Thus, for a given SNR, the proposed technique has lower MSE at all SNRs. It is also observed that, by using wavelet packet analysis technique, the proposed technique can estimate local statistics of the noise power when the noise is colored. The proposed estimator fulfills the criteria of a good SNR estimator because it is unbiased (or exhibits the smallest Bias) and has the smallest variance of SNR estimates as shown from results clearly.

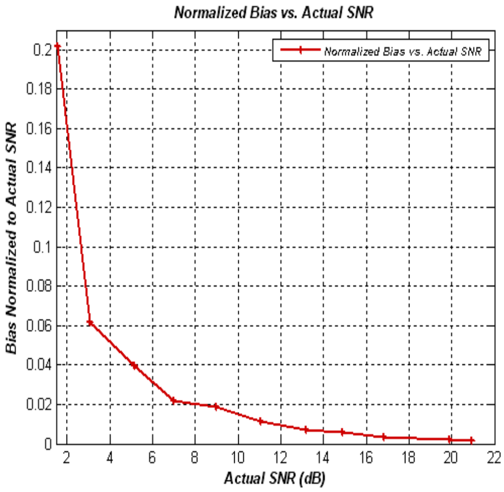

Figure 7: Olot of Normalized Bias vs. Actual SNR.

The proposed front-end estimator has relatively low computational complexity (~$2N^3$) because it makes use of only one OFDM preamble signal and relies on the autocorrelation of the same to find the SNR estimates. Reddy's estimator has relatively more computational complexity (~$50N^3$) as compared to proposed estimator as its works after FFT and makes use of 50 OFDM symbols to find the SNR estimates.

5 CONCLUSIONS

In this paper, a novel front-end noise power and SNR estimation technique using wavelet-packets is presented. Also, variation of the noise power across OFDM sub-carriers is allowed. Therefore, the proposed approach estimates both local (within smaller sets of subcarriers) and global (over all sub-carriers) SNR values. The short term local estimates calculate the noise power variation across OFDM sub - carriers. These estimates are specifically very useful for diversity combining, adaptive modulation, and optimal soft value calculation for improving channel decoder performance. Its performance has been evaluated via computer simulations using AWGN and multipath fading channels and implemented in OFDM systems. The results show that the current estimator performs better than other conventional methods. Complexity to find SNR estimates is lower because the current estimator makes use of only one OFDM preamble signal. The current estimator fulfills the criteria of good SNR estimator as it is unbiased and has the smallest variance of SNR estimates.

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