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SNR Estimation Algorithm for OFDM Systems

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Abstract – This paper presents a SNR estimation method for OFDM systems. The OFDM training symbols in the OFDM data are equalized by the known data in frequency domain and employed to estimate the noise variance. The second order moments of the received symbols are used to estimate the signal plus noise power in the OFDM packets. The SNRs on the subchannels and the average SNR of the packets can all be estimated. Simulation results show that the proposed method is robust to frequency selectivity in wireless channels, and its performance is considerably improved compared with the available methods.

Index Terms – OFDM. SNR, MMSE, Variance

1. INTRODUCTION

Signal-to-Noise Ratio (SNR) estimation [1] is very important for wireless OFDM systems since the proper operations of many key techniques for improving system performance, such as adaptive coding and modulation soft decoding procedures, mobile assisted handoff, and channel assignment, are strongly dependent on the correct estimation of SNR. There are many available algorithms for SNR estimation with high performance for single carrier systems in additive white Gaussian noise (AWGN) channels, such as maximum likelihood (ML) algorithm, minimum mean square error (MMSE) algorithm [1], and moment based algorithm. Most of them can also be used to estimate the SNR of OFDM signal in AWGN channels. But in wireless channels, these algorithms cannot be directly applied in OFDM systems for the coefficients of the sub channels are different and slowly changing. Only in recent years, attention has been focused on the SNR estimation in wireless OFDM systems, and several SNR estimation algorithms have been presented by using the samples of the OFDM data.

OFDM has evolved from the earliest forms of frequency-division multiplexing (FDM). FDM was conceived in order to allow the simultaneous transmission [2] of multiple signals over a wide bandwidth channel utilizing separate carrier frequencies. The trouble with conventional FDM systems is that they do not efficiently utilize the available bandwidth because there is no spectral overlap between adjacent carriers. This waste is further aggravated by the addition of guard bands (areas of no spectral content between carriers) necessary to ensure no frequency domain overlap and to make filtering at the receiver practical. Rather than transmitting completely separate signals, each on their own carrier frequency, as with conventional FDM, the concept of OFDM [3] is to divide the bits of a single high-data rate transmission into many lower-data rate bit streams through serial-to-parallel conversion. The resulting lower-data rate bit streams are then modulated and transmitted on multiple carrier frequencies. The orthogonality, or precise peak-to-null frequency spacing, of these multiple carriers the so called “sub-carriers”, and the ensuing spectral overlap is what sets OFDM apart from its predecessors. Modern signal processing techniques such as the fast Fourier transform (FFT) have made implementation of OFDM realizable. The main objective of this work is to Estimate the SNR on each sub channel of the OFDM packet and compared with the existing methods.

The paper is organized as follows. In Section 2, the fundamentals of OFDM system and its main features are discussed. Then in Section 3, the existing SNR estimation methods are explained. Section 4 introduces the proposed method and finally Section 5 gives the comparison results followed by conclusion.

2. OFDM System Model for SNR Estimation

An OFDM system model is used here to estimate the SNR. The system model is shown in Fig. 1. The transmitter and receiver of the OFDM system model is considered to estimate the SNR using various parameters.

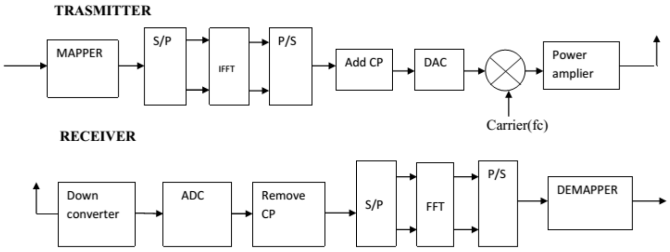

Figure 1 OFDM System Model

Conventionally, the multi-carrier transmitter consists of a set of modulators, each with different carrier frequencies. The transmitter then combines the modulator outputs and generates the transmitted signal. Suppose that the N data to be transmitted are X_k,k = 0,1,2,3,…..N-1, where X_k is a complex number in a given constellation, such as QPSK or QAM. Also suppose that the kth carrier frequency for $X_k$is f_k.

Then, the complex-valued multi-carrier transmitter output is given by

$$x(t) = \sum_{k=0}^{N-1} X_k \, e^{j2\pi f_k t} \qquad (1)$$

Modern communication systems often implement their transmitters and receivers digitally whenever they can. A digital transmitter will generate its output in a sampled-data fashion. By letting t = nT_s, where T_s is the sample interval, the digital multi-carrier transmitter output becomes

$$x(nT_s) = \sum_{k=0}^{N-1} X_k \, e^{j2\pi f_k n T_s} \qquad (2)$$

Furthermore, if the carrier frequencies are uniformly spaced in the frequency domain by a frequency spacing of f_s, i.e. $f_k = kf_s$; k = 0; 1; . . . ; N 1, then

$$x(nT_s) = \sum_{k=0}^{N-1} X_k \, e^{j2\pi k f_s n T_s} \qquad (3)$$

Let the $f_s = 1/(NT_s)$ minimum separation to keep orthogonality among signals on different modulators–then the OFDM signal is given by

$$x_n = x(nT_s) = \sum_{k=0}^{N-1} X_k \, e^{j2\pi k/N} \qquad (4)$$

These carriers are called subcarriers and usually there is one more modulation to translate all these subcarriers to a higher frequency band. Except for a multiplying constant (1=N), the above formula is the equation of an N-point inverse discrete Fourier transform(IDFT). If Nis a power of two, then there exist many fast and efficient algorithms and architectures for implementing such an IDFT operation. It is such efficient digital realization of the OFDM transmitter that makes the OFDM technology a feasible solution to advanced communication systems.

3. SNR Estimation Methods

The entire proposed modelling and architecture [4] of the current research paper should be presented in this section.

3.1. Existing SNR Estimation Algorithms

- Maximum Likelihood Algorithm

The principle of maximum likelihood is relatively straightforward. As before, we begin with a sample X = (X1, . . . , Xn) of random variables chosen according to one of a family of probabilities Pθ. In addition, f(x|θ), x = (x1, . . . , xn) will be used to denote the density function for the data when θ is the true state of nature. Then, the principle of maximum likelihood yields a choice of the estimator ˆθ as the value for the parameter that makes the observed data most probable.

The likelihood function is the density function regarded as a function of θ.

$$L(\theta|x) = f(x|\theta)$$

The maximum likelihood estimator (MLE), θ(x) = arg max θ L(θ|x). We will learn that especially for large samples, the maximum likelihood estimators have many desirable properties. However, especially for high dimensional data, the likelihood can have many local maxima. Thus, finding the global maximum can be a major computational challenge. This class of estimators has an important property. If θ(x) is a maximum likelihood estimate for θ, then g(θ(x)) is a maximum likelihood estimate for g(θ). For example, if θ is a parameter for the variance and ˆθ is the maximum likelihood estimator, then p ˆθ is the maximum likelihood estimator for the standard deviation. This flexibility in estimation criterion [5] seen here is not available in the case of unbiased estimators. Typically, maximizing the score function, lnL(θ|x), the logarithm of the likelihood, will be easier. Having the parameter values be the variable of interest is somewhat unusual, so we will next look at several examples of the likelihood function.

- Minimum Mean-Square Error (MMSE) Method

The minimum mean-square error (MMSE) of estimating an arbitrary random variable from its observation contaminated by Gaussian noise. The MMSE [6] can be regarded as a function of the signal-to-noise ratio (SNR) as well as a functional of the input distribution (of the random variable to be estimated). It is shown that the MMSE is concave in the input distribution at any given SNR. For a given input distribution, the MMSE is found to be infinitely differentiable at all positive SNR, and in fact a real analytic function in SNR under mild conditions. The key to these regularity results is that the posterior distribution conditioned on the observation through Gaussian channels always decays at least as quickly as some Gaussian density. Furthermore, simple expressions for the first three derivatives of the MMSE with respect to the SNR are obtained. It is also shown that, as functions of the SNR, the curves for the MMSE of a Gaussian input [7] and that of a non-Gaussian input cross at most once over all SNRs. These properties lead to simple proofs of the facts that Gaussian inputs achieve both the secrecy capacity of scalar Gaussian wiretap channels and the capacity of scalar Gaussian broadcast channels, as well as a simple proof of the entropy power inequality in the special case where one of the variables is Gaussian.

- Boumard Method

In this method a new noise variance and SNR estimation algorithm for a 2 × 2 MIMO wireless OFDM system. The SNR information is used to adapt parameters or reconfigure parts of the transmitter. The noise variance estimation algorithm uses only two OFDM training symbols from each transmitting antenna and the FFT output signals at the receiver. It does not require knowledge of the channel coefficients [8]. Then, using the channel coefficient estimates given by a channel estimator and the estimate of the noise variance, the SNR is computed. The algorithm's performance is measured through Monte-

Carlo simulations on a variety of channel models and compared to those of an MMSE algorithm using perfect channel estimates. The normalized MSE of the obtained noise variance estimate shows good results as long as the delay spread of the channel is small enough compared to the OFDM symbol period.

The estimation of the SNR on each subcarrier as well as the overall SNR is the focus of this paper. The accuracy and reliability of the SNR estimates are important as the performance of the whole system depends on them, through the use of adaptivity and reconfigurability.

Through the transmission of training symbols, we must acquire an estimate of the SNR. Noise variance and hence SNR estimation is an old topic. Various authors have been focusing on this problem, mainly for single-input single-output single carrier systems. The main areas of applications are adaptive schemes, for example, and turbo decoding, as in. The estimation algorithms mostly focus on constant amplitude modulations, as quadrature phase shift keying (QPSK). Minimum mean square error (MMSE) and maximum likelihood (ML)-based noise variance estimators [2] use channel estimates whereas moment based algorithms are blind, as well as many ad-hoc algorithms, as presented in and. Their algorithm is used for turbo decoding and has a long averaging interval. Our goal is rather different, as we need to acquire the SNR during the acquisition mode, using a limited amount of data. We thus have not found any trace of earlier research on our particular problem. We will also show that during acquisition, we cannot use a simple MMSE algorithm for the noise variance estimation due to the choice for the channel estimator. This is why we had to think of a new algorithm for noise variance estimation [8] and hence SNR estimation. In order to get an estimate of the SNR using the training symbols, we present herein a new algorithm for estimating the noise variance that does not require any knowledge about the channel coefficients. It uses only the signals at the output of the FFT at the receiver. It can be applied together with the channel estimator. For example, to calculate the SNR. The performance of this new algorithm is evaluated through simulations. We first present the system model by focusing on the acquisition mode, meaning the transmission of known training data. Different channel models are used to test and study the performance and limits of the algorithm. And then present the new algorithm, together with the MMSE algorithm, which will be used for comparison.

4. Proposed Method

In the proposed method, the noise variance is estimated with the received data of the training OFDM symbols, and the signal power is estimated with the second moment of the received data of the OFDM symbols in the packet. The SNRs on the sub channels and the average SNR of the packet can all be estimated by the proposed method.

4.1. Signal model

In the packet-oriented OFDM system, the mth transmitted complex OFDM symbols in frequency domain can be represented as

Cm = [cm,0,cm,1,...,cm,k,...,cm,N−1], (where N is the size of IFFT, and cm,k is the complex modulated symbol on the kth sub-carrier during the mth OFDM symbol. If the cyclic prefix (CP) is at least four times longer than the maximum delay spread of the wireless channels [9], and the synchronization is perfect at the receiver, after FFT transform, the kth subcarrier output of the mth OFDM symbols can be given as

$$Y_{m,k} = C_{m,k} H_{m,k} + n_{m,k} \tag{1}$$

where nm,k is the sample of zero-mean complex Gaussian noise process with variance W, and assumed to be independent of the sub-carrier index k, and

$$H_{m,k} = H\left(mT, \frac{k}{T}\right) = \frac{1}{\sqrt{N}} \sum_{m=0}^{L-1} h(mT, lTs) . e^{-j2\Pi klTs/T} \tag{2}$$

$$h(mT, lTs) . e^{-j2\Pi klTs/T}$$

where $h(mT, lTs)$ denotes the discrete samples of the complex impulse response of the wireless channel during the mth OFDM symbol, T is the period of the OFDM symbol, Ts is the sampling period at the receiver, and G is the length of samples of the complex impulse response of the wireless channel.

4.2. Proposed Algorithm Steps

Step1: The Noise Variance Estimation

Step2: SNR Estimation

- The Noise Variance Estimation:

The preambles are different in the available OFDM transmission standards. But in most standards, the preamble often contains two or more OFDM symbols with the same structure, or one OFDM symbol with many identical parts. The adjacent OFDM training symbols [10] with the same structure or the identical parts in one OFDM symbol are employed in the proposed method to estimate the noise variance.

First, we derive the estimation of the noise variance by using the two adjacent OFDM training symbols with the same structure.

$$Y_{m,k} = C_{m,k} H_{m,k} + n_{m,k} \tag{3}$$

$$Y_{m+1,k} = C_{m+1,k} H_{m+1,k} + N_{m+1,k} \tag{4}$$

Where m and (m+1) are received OFDM training symbols [12] in the preamble.

Where $n_{m,k}$, is the sample of zero-mean complex Gaussian noise process with variance.

$$H_{m,k} = H\left(mT, \frac{k}{T}\right) = \frac{1}{\sqrt{N}} \sum_{m=0}^{L-1} h(mT, lTs).\, e^{-j2\Pi klTs/T} \quad (5)$$

When $c_{m,k} = 0$,

Let $$y'_{m,k} = y_{m,k} . c_{m,k} = h_k + n'_{m,k} \quad (6)$$

$$y'_{m+1,k} = y_{m+1,k} . c_{m+1,k} = h_k + n'_{m+1,k} \quad (7)$$

When $c_{m,k} = 0,\ Let\ \ y'_{m,k} = y_{m,k} = n'_{m,k}$ (8)

$$y'_{m+1,k} = y_{m+1,k} = n'_{m+1,k} \quad (9)$$

By using below equations we can find out Noise Variance

$$E\left\{\left\| y'_{m,k} - y'_{m+1,k} \right\|^2\right\} \quad (10)$$

$$E\left\{\left\| n'_{m,k} - n'_{m+1,k} \right\|^2\right\} = 2\text{W} \quad (11)$$

Therefore, the noise variance can be estimated by

$$\text{W} = \frac{E\left\{\left\| n'_{m,k} - n'_{m+1,k} \right\|^2\right\}}{2} \quad (12)$$

- SNR Estimation

The second order moment of can be described as

$$m_{2,k} = E\left\{\left\| y'_{m,k} \right\|^2\right\} = E\left\{\left\| c_{m,k} . H_k \right\|^2\right\} + E\left\{\left\| n'_{m,k} \right\|^2\right\}$$

$$m_{2,k} = P_k + \text{W} \quad (13)$$

where P_k is the power of the signal of the kth sub-channel.

The signal power on the kth sub channel can be estimated as

$$m_{2,k} - \text{W} = P_k \quad (14)$$

Thus the SNR on the kth sub channel is estimated with

$$\widehat{\rho_k} = \frac{\widehat{m_{2,k}}}{\widehat{W}} - 1 \quad (15)$$

Where

$$\widehat{m_{2,k}} = \frac{1}{L} \sum_{m=0}^{L-1} \left\{\left\| y'_{m,k} \right\|^2\right\}$$

The expectation of the estimated SNR on the kth sub channel can be given as

$$£\{\widehat{\rho_k}\} = £\left\{\frac{\widehat{m_{2,k}}}{\widehat{W}} - 1\right\} = \rho_k \quad (16)$$

The mean square error of the estimated SNR on the kth sub channel is

$$\text{MSE}\{\widehat{\boldsymbol{\rho_K}}\} = £\left\{\left(\boldsymbol{\rho_k} - \widehat{\boldsymbol{\rho_k}}\right)^{\mathbf{2}}\right\} = \boldsymbol{var}\{\boldsymbol{Z}\} \quad (17)$$

The average SNR of the packet can be estimated with

$$\widehat{\boldsymbol{\rho_{avg}}} = \frac{\mathbf{1}}{\boldsymbol{N}} \sum_{\boldsymbol{N=0}}^{\boldsymbol{N-1}} \{\widehat{\boldsymbol{\rho_k}}\} \quad (18)$$

The mean square error of the average SNR of the received OFDM packet

$$\text{MSE}\{\widehat{\boldsymbol{\rho_{avg}}}\} = £\left\{\left(\boldsymbol{\rho_{avg}} - \widehat{\boldsymbol{\rho_{avg}}}\right)^{\mathbf{2}}\right\} \quad (19)$$

We can calculate SNR for OFDM by using above equations.

5. Simulation Results

The performance of the proposed SNR estimation method has been evaluated with computer simulation.

5.1. Simulation Parameters

The simulation parameters used in the wireless OFDM system are taken from IEEE802.16 metropolitan area network (MAN) standard. The number of sub channel is 4, and the length of the cyclic prefixis32samples.The sampling frequency is 10 MHz The OFDM training symbols are used in the OFDM packets. The modulated data in the training OFDM symbols are the constant amplitude zero autocorrelation (CAZAC) sequences. The performance of the proposed SNR estimation on the sub channel is investigated in the wireless channel models with different delay spreads and Doppler shifts.

Average SNR estimation by the proposed method, Boumard's method and Xu's method are simulated and compared with each other in channel A. For Boumard's method, the data used in the packet is the same as that in proposed technique. The range of the SNR estimation is set from -10 dB to 40 dB unless stated otherwise, 100 000 simulation runs will be applied.

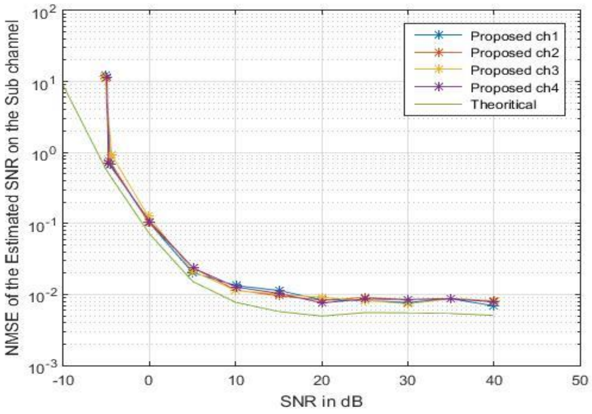

Figure 2 SNR vs NMSE

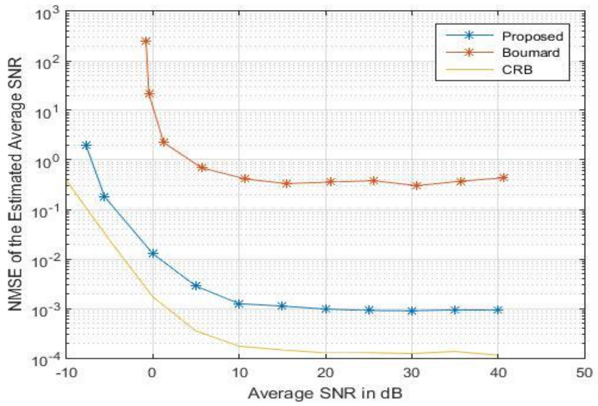

Figure 3 Average SNR vs NMSE

5.2. Performance of the SNR Estimation

Fig 2. shows the normalized mean square errors (NMSEs) of the SNR estimation on the sub channel by the proposed method in the four channels. It can also be seen that the NMSEs of the proposed method decrease as the packet length L increases. Shows the NMSEs of the average SNR estimation by the new proposed method, Boumard's method in channel A with the packets of the same length. A solid line in the figure shows the CRB values of the SNR for comparison. It is seen from Fig. 3 shows that the NMSEs of the new algorithm approach the CRB when the SNR is greater than 15dB, and are much less than those of Boumard's method. The NMSEs of Boumard's method increase rapidly due to the difference between the coefficients of the adjacent sub channels in the frequency domain when the SNR is greater than 20dB, which reveals that Boumard's method is very sensitive to frequency selectivity of wireless channel.

6. CONCLUSION

In this paper a new SNR estimation method for OFDM systems in the frequency selective channels is proposed. The requirement is that it should contain two adjacent OFDM symbols with the same structure or one OFDM symbol with two identical parts. The SNRs on the sub channels and the average SNR of the packet can all be estimated. Simulation results show that the performance of the SNR estimation on the sub channel by the proposed method is the same as that in the theoretic analysis, and the performance of the average SNR estimation by the proposed method is much better than that of the available methods. The proposed method can also be applied in a linear equalized MIMO-OFDM system when the required OFDM training symbols in the preambles are transmitted at each transmit antennas.

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