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Procedia Engineering 29 (2012) 3124 – 3131

Procedia Engineering

www.elsevier.com/locate/procedia

2012 International Workshop on Information and Electronics Engineering (IWIEE)

An Improved SNR Estimator for Wireless OFDM Systems

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Abstract

SNR is a crucial parameter for OFDM system and the assistant technology thereof such as Turbo coding, channel equalization. In this paper, we propose an improved SNR estimator which can be applied for the pilot structure in 3GPP standard. The modified second order moments of the pilot points after FFT are used to estimate noise variance in OFDM packets. The channel frequency responses of four subcarriers from adjacent two pilot points in distinct symbols could be used to inhibit the channel fading. Simulation results show that the proposed algorithm is robust to frequency selectivity and time selectivity in wireless channels, and its performance is considerably improved compared with the available methods.

Key Words: OFDM, SNR estimation, MBSFN, time and frequency selectivity

1. Introduction

The system of orthogonal frequency division multiplexing (OFDM) is an important technology, which is widely applied in the contemporary communication field, such as 802.16 protocol, WiMAX, LTE. As an indicator of channel quality, signal to noise ratio (SNR) is a pivotal parameter for OFDM. It can be harnessed for improving performance in many techniques, such as cognitive radio, adaptive coding, decoding, and channel estimation. Defined as the signal energy to noise power ratio, SNR is divided into the average SNR and the subcarrier SNR. Average SNR is the mean for all the subcarriers, the SNR of which can be obtained through the channel estimation.

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This work is supported by “ Fundamental Research Funds for the Central Universities ” , No.ZYGX2009J006 and No.ZYGX2010J006

doi:10.1016/j.proeng.2012.01.452

In term of Multicast Broadcast Single Frequency Network (MBSFN), mobile terminal receives the same data from different base stations in down-link. It seems that a signal from one station through multipath fading channel. This model belongs to typical frequency selectivity fading channel. If the user moves fast, the time selectivity fading could also decrease the SNR estimation.

There are two categories of SNR estimators, data-aided (DA) estimators [1-4] and blind estimators[5]. DA estimators are based on known data at the receiver to estimate noise power and signal energy, which are used to figure out SNR. Two kinds of known data could be employed: one is the preamble for synchronization and channel estimation, which consists of one or more OFDM symbols with special structure; the other is the pilot as some designated subcarriers in the symbol. However, blind estimators utilize the received data to get out SNR value at the cost of trading performance and accuracy and meanwhile slowing convergence velocity.

In additive white Gaussian noise (AWGN) channel, both the estimator of maximum likelihood (ML) in the literature [6] and the minimum mean square error (MMSE) algorithm in the work [7] both have good performance in SNR estimation, but neither of them can work in the wireless channel. Boumard proposed a preamble-based algorithm in 2×2 MIMO-OFDM system[4] on the assumption that the channel coefficients on adjacent subcarriers are the same, but the performance was lost in multipath channel featured with high frequency selection. In contrast, G.L. Ren utilized that the frequency responses of different symbols on the same subcarrier were approximately equal to estimate noise variance[2]. However, the Doppler frequency shift and huge blank between the OFDM symbols could cause great error. Based on autocorrelation and cross-correlation of pilot data, H.L. XU proposed a novel estimator[3], while the algorithm resorted to comb pilot and its performance was dependent on the number of pilots. Milan Zivkovic estimated noise power by the subcarriers without data[5] and Y.X. Lin chose bracer.

In this paper, we propose an improved algorithm based on Boumard's and Ren's estimators. In term of comb pilot, we select adjacent pilot points from different OFDM symbols to estimate the noise variance by means of utilizing the compensation characteristics of channel coefficient. Though with more $2N$ multiplications and N additions than Boumard's or Ren's estimator, it could offset the time selectivity fading and frequency selectivity fading. Compared with Boumard's and Ren's algorithms, it possesses a better performance.

The subsequent contents are organized as follows: in Section 2, the system model and the pilot structure are architected; in Section 3, Boumard's and Ren's algorithms are introduced; in Section 4, the novel estimator is proposed; the comparison and analysis by computer simulation are drawn in Section 5 and the summary is afforded in Section 6.

2. System model

In OFDM system, the sending data in frequency domain are expressed as

$$D=[d_{m,0},d_{m,1},d_{m,2},\cdots,d_{m,n},\cdots,d_{m,N-1}] \tag{1}$$

where $d_{m,n}$ is a complex modulated and energy-normalized signal on *n*th subcarrier during *m*th OFDM symbol. N is the size of IFFT. Under the premise that the cyclic prefix (CP) is long enough and the synchronization is perfect at the receiver, the signal at the receiver in frequency domain through the multipath wireless channel and AWGN can be described as

$$Y_{m,n}=H_{m,n}d_{m,n}+\eta_{m,n} \tag{2}$$

where $H_{m,n}$ is the frequency response of channel, $\eta_{m,n}$ is the sample of zero-mean complex Gaussian noise process.

From formula (2), the transmitted signal energy could be figured out by the equation $S = E\{H_{m,n} d_{m,n}\}$ and the noise power is $W = E\{\eta_{m,n}\}$, where $E\{\bullet\}$ denotes the operation of the conditional expectation. And then the SNR can be expressed as $\rho = S / W$.

The reference [8] shed light on the pilot structure of OFDM data frame in 3GPP standard about LTE technology in Fig.1. In light of the block pilot, two pilot symbols are separated from each other by three OFDM data symbols. The places of the pilots in the second pilot symbol using the QPSK modulation are staggered with the others.

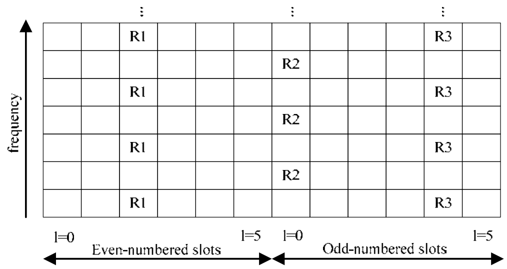

Fig.1.The structure of pilot in 3GPP

3. SNR estimators

3.1. Boumard Algorithm

In the literature [4], Boumard proposed an estimator for 2×2 MIMO channel OFDM system. This method takes advantage of 4 special preambles. Then work [9] showed the version of Boumard algorithm in SISO system. Boumard algorithm adopted second-order moment estimation.

The noise variance is

$$\hat{W} = \frac{1}{2NM} \sum_{m=1}^{M} \sum_{n=1}^{N-1} \left| Y_{m,n-1} d_{m,n} - Y_{m,n} d_{m,n-1} \right|^2 , \tag{3}$$

and the average signal energy is

$$\hat{S} = \frac{1}{MN} \sum_{m=1}^{M} \sum_{n=0}^{N-1} \left| \frac{Y_{m,n}}{d_{m,n}} \right|^2 , \tag{4}$$

where M is the number of the OFDM symbols. Then the estimated SNR is expressed as $\hat{\rho} = \hat{S} / \hat{W}$. The algorithm used an assumption that the channel frequency responses of adjacent subcarriers are approximately equal, that is $H_{m,n-1} \approx H_{m,n}$. So the channel must vary slowly in the frequency domain.

3.2. Ren's Algorithm

Seen from the prerequisite, high sensitivity to frequency selectivity is the main disadvantage of Boumard algorithm. In the work [2], Guangliang Ren proposed a novel SNR estimator based on 2 preambles with the same structure, which also adopted second-order moment but was more robust to multipath effect.

When $d_{m,n} \neq 0$, let $Y'_{m,n} = Y_{m,n} d^*_{m,n} = H_{m,n} + \eta_{m,n} d^*_{m,n}$. (5)

When $d_{m,n} = 0$, let $Y'_{m,n} = Y_{m,n} = \eta_{m,n}$. (6)

The noise variance can be expressed by

$$\hat{W} = \frac{1}{2N}\sum_{n=0}^{N-1}\left|Y'_{m,n} - Y'_{m+1,n}\right|^2 , \tag{7}$$

and the power of received data signal is

$$\hat{P} = \frac{1}{MN}\sum_{n=0}^{N-1}\sum_{m=1}^{M}\left|Y_{m,n}\right|^2 . \tag{8}$$

The estimated SNR is expressed as $\hat{\rho} = (\hat{P} - \hat{W}) / \hat{W}$. It must be used in slow-fading channel which could be assumed that $H_{m,n} \approx H_{m+1,n} \approx H_n$.

4. Proposed estimator

Because the Boumard estimator is based on the assumption that the coefficients of adjacent subchannels in the frequency domain are the same and it is sensitive to the delay spread. The increase of the multipath number causes high frequency selectivity, which makes the performance of the estimator decrease. However, Ren's algorithm is influenced by time selectivity and is also applied to slow-varying channel. Under the influence of Doppler effect, the channel frequency responses of different OFDM symbols on the same subcarrier alter. When the Doppler shifts are large, the error can not be ignored. Besides, it can lower the performance that the pilot symbols are not adjacent like party 2. In this paper, an improved algorithm is proposed based on Boumard's and Ren's estimator. It estimates SNR from adjacent pilot points of different OFDM symbols. This novel estimator offsets the effort of time selectivity fading and frequency selectivity fading, which gets a more accurate SNR estimation.

Similar to Boumard's and Ren's algorithms, we select 2 OFDM symbols and a new formula is defined as

$$\begin{aligned}&(Y_{m,n}d^*_{m,n} - Y_{m,n+1}d^*_{m,n+1}) - (Y_{m+1,n}d^*_{m+1,n} - Y_{m+1,n+1}d^*_{m+1,n+1}) \\ &= [(H_{m,n} - H_{m,n+1}) - (H_{m+1,n} - H_{m+1,n+1})] + [(\eta_{m,n}d^*_{m,n} - \eta_{m,n+1}d^*_{m,n+1}) - (\eta_{m+1,n}d^*_{m+1,n} - \eta_{m+1,n+1}d^*_{m+1,n+1})]\end{aligned} \tag{9}$$

There exists the error of $H_{m,n} - H_{m,n+1}$ in Boumard estimator, while $H_{m,n} - H_{m+1,n}$ in Ren's estimator. In the proposed algorithm, $(H_{m+1,n} - H_{m+1,n+1})$ is used to offset the difference between adjacent subchannels and decrease the error in the estimation of noise power. We can know that the result of $[(H_{m,n} - H_{m,n+1}) - (H_{m+1,n} - H_{m+1,n+1})]$ is more close to zero. However, it is different from the formula of average estimation based on two preambles for Boumard algorithm, which could lead to doubling in error. It can't be regarded as the average of Ren's estimation, because neither of the established estimators offsets the channel coefficient. Simple average of Boumard's or Ren's algorithm increases the error instead of accurate value. We get expectation for *(9)*

$$\begin{aligned}&E\{\left|(Y_{m,n}d^*_{m,n} - Y_{m,n+1}d^*_{m,n+1}) - (Y_{m+1,n}d^*_{m+1,n} - Y_{m+1,n+1}d^*_{m+1,n+1})\right|^2\} \\ &= E\{\left|(\eta_{m,n}d^*_{m,n} - \eta_{m,n+1}d^*_{m,n+1}) - (\eta_{m+1,n}d^*_{m+1,n} - \eta_{m+1,n+1}d^*_{m+1,n+1})\right|^2\} \\ &= 4W\end{aligned} \tag{10}$$

Therefore, the noise power is estimated as

$$\hat{W} = \frac{1}{4(N-1)}\sum_{n=0}^{N-2}\left|(Y_{m,n}d^*_{m,n} - Y_{m,n+1}d^*_{m,n+1}) - (Y_{m+1,n}d^*_{m+1,n} - Y_{m+1,n+1}d^*_{m+1,n+1})\right|^2 . \tag{11}$$

And the signal energy is expressed as $\hat{S} = \frac{1}{MN}\sum_{n=0}^{N-1}\sum_{m=1}^{M}\left|Y_{m,n}\right|^2 - \hat{W}$. *(12)*

Thus the estimated average SNR is $\hat{\rho} = (\hat{P} - \hat{W}) / \hat{W}$. *(13)*

From the work [9], the SNR for kth subcarrier could be estimated by the average and the channel estimation. It was expressed as $\hat{\rho}_k = \hat{\rho}\left|\hat{H}_k\right|^2$, where $\hat{H}_k$ is the channel estimation for *k*th subcarrier through maximum likelihood (ML) algorithm.

From part 2, the pilot structure in 3GPP is special. The places of pilot subcarriers on the second pilot symbol differ from another two, and then two situations are born: one is choosing the adjacent pilot symbols called AP algorithm and the other is selecting the nonadjacent pilot symbols, which is abbreviated to NP algorithm.

4.1. AP algorithm

When the Doppler frequency is large, the time selectivity results in big gap between the channel parameters of different symbols. The blank between two pilot symbols is the main factor influencing the performance. In this condition, AP estimator is better. So we choose $Y_{3,n}Y_{7,n}$ and $Y_{7,n}Y_{11,n}$, getting the average value after respectively calculating the SNR. Then the estimation of noise power is expressed as

$$\hat{W} = \frac{1}{8(N/2-1)}\sum_{j=1}^{N/2}\Big[\left|(Y_{3,2j}d^*_{3,2j} - Y_{3,2j+2}d^*_{3,2j+2}) - (Y_{7,2j-1}d^*_{7,2j-1} - Y_{7,2j+1}d^*_{7,2j+1})\right|^2 + \left|(Y_{7,2j-1}d^*_{7,2j-1} - Y_{7,2j+1}d^*_{7,2j+1}) - (Y_{11,2j}d^*_{11,2j} - Y_{11,2j+2}d^*_{11,2j+2})\right|^2\Big] . \qquad (14)$$

The signal energy is the same as above.

4.2. NP algorithm

When the Doppler frequency is small, the channel frequency response on different symbols is stable. The error of different pilot subcarrier becomes the primary consideration. Thus NP estimator could have better performance. The estimation of noise power is described as

$$\hat{W} = \frac{1}{4(N/2-1)}\sum_{j=1}^{N/2}\left|(Y_{3,2j}d^*_{3,2j} - Y_{3,2j+2}d^*_{3,2j+2}) - (Y_{11,2j}d^*_{11,2j} - Y_{11,2j+2}d^*_{11,2j+2})\right|^2 . \qquad (15)$$

5. Simulation results

5.1. Simulation condition

The performance of the proposed estimator in this paper is compared with the performance of Boumard's and Ren's estimator using Monte-Carlo model through computer simulation. The simulation parameters are adopted from 3GPP standard[8] and the structure of pilot is shown as Fig.1. The number of subcarrier $N = 512$ includes 300 points data, and the others are guard band. The cyclic prefix length is $N/4$ and the sampling frequency is $7.68MHz$. Referring to standard[10], the performance is evaluated by two channel model, EVA and ETU. The detailed channel delay and average power are given in Table.1. The coefficients of all the taps in the channels are subject to Rayleigh fading and the maximum Doppler frequency (f_d) is listed in Table.2.

The number of independent trials is set at $N_t = 100000$ assuring the high confidence interval of the estimates. The normalized mean square error (NMSE) is defined as the following formula

$$NMSE = \frac{1}{N_t}\sum_{t=1}^{N_t}\left(\frac{\hat{\rho}_t - \rho}{\rho}\right)^2 \qquad (16)$$

where $\hat{\rho}_t$ is the estimation of SNR in the *t*th trail and ρ represents the true value. NMSE exhibits the performance of the algorithm.

Table.1 The average power and delay of the channels

Model	Average power (*dB*)	Delay ($\times 10^{-9}s$)
EVA	0, -1.5, -1.4, -3.6, -0.6, -9.1, -7.0, -12.0, -16.9	0, 30, 150, 310, 370, 710, 1090, 1730, 2510
ETU	-1.0, -1.0, -1.0, 0.0, 0.0, 0.0, -3.0, -5.0, -7.0	0, 50, 120, 200, 230, 500, 1600, 2300, 5000

Table.2 The maximum Doppler frequency of the channels

Model	Maximum Doppler frequency
EVA 5Hz	5 Hz
EVA 70Hz	70 Hz
ETU 70Hz	70 Hz
ETU 300Hz	300 Hz

5.2. Performance

For the structure shown in Fig.1, Boumard algorithm needs to collect the received data of the pilot point after Fast Fourier Transformation (FFT).And for Ren's algorithm, the first and third pilot symbols are chosen because the second one has a different structure.

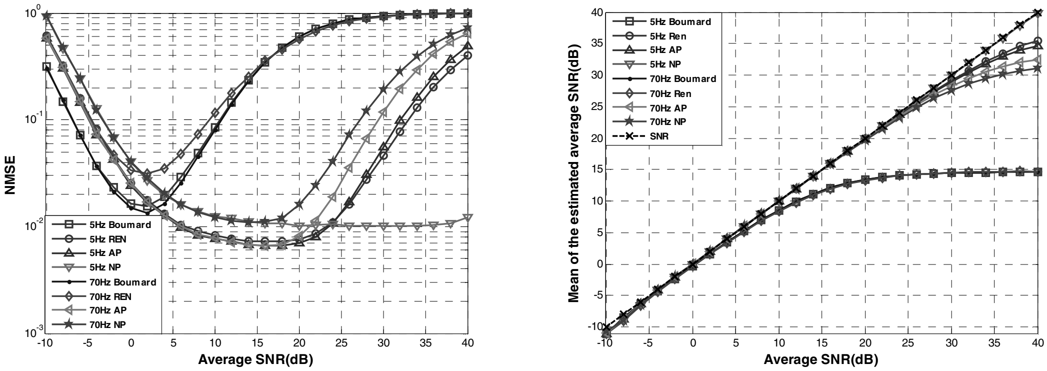

Fig.2. (a) NMSE of the average SNR in EVA channel; (b) Mean of the estimated average SNR in EVA channel

Fig.2 and Fig.3 respectively show the NMSE and the estimated average SNR of the SNR estimations by the above four algorithms on EVA channel model with $5Hz$ and $70Hz$ as maximum Doppler frequency. It can be seen that Boumard's method is robust to time frequency, but its performance is poor in frequency selective channel when the SNR is larger than $10dB$. When $f_d = 5Hz$, the estimation of NP almost coincides with the straight line of the real SNR. Ren's estimator has a good performance, but after 30dB, the error becomes larger. When $f_d = 70Hz$, Ren's is the same as Boumard's, while AP performs best.

As shown in Fig.3 (a) and (b), the NMSE and the estimated average SNR after the SNR estimations by the above four algorithms on ETU channel model with $70Hz$ and $300Hz$ as maximum Doppler frequency are afforded. In the condition that f_d is $70Hz$, the performance of NP is better than AP; when SNR is greater than $15dB$, they are more accurate than Boumard's or Ren's algorithm; however, when

$f_d = 300Hz$, AP is better than NP and Ren’s algorithm can’t estimate SNR at any point. Above all, the new estimator is robust to time and frequency selectivity and when the maximum Doppler frequency is great, AP is better than NP.

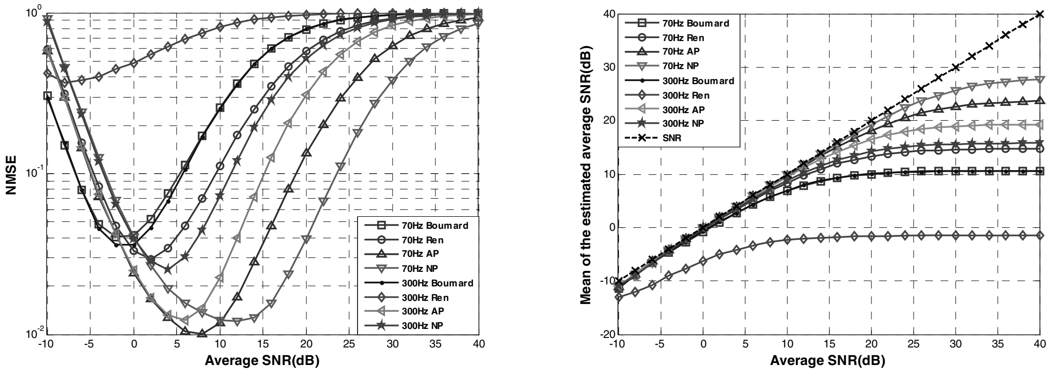

Fig.3. (a) NMSE of the average SNR in ETU channel; (b) Mean of the estimated average SNR in ETU channel

6. Conclusions

In this paper, a novel SNR estimation algorithm utilizing pilot symbols is proposed for MBSFN systems, which is generated from Boumard’s and Ren’s algorithm. The adjacent pilots on different OFDM symbols are utilized to estimate noise power and the whole symbols are used to estimate signal energy. From the simulation, it can be confirmed that the improved algorithm is better than Boumard’s estimator in high frequency selectivity. On another hand, it has better performance than Ren’s estimator with large Doppler spread, and the in this condition, NP is worse than AP.

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