Performance Analysis of New SNR Estimation Methodology based on Preamble Approach

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Abstract: The latest wireless communication systems focus on developing MIMO-OFDM systems that allow the transmission of very high data rates in fading environments. We can optimize these systems even further by setting the modulation and coding adaptively according to the channel conditions, and by using sub-carrier frequency and power allocation techniques. The overall system performance depends on the accuracy and delay of the channel state information (CSI). In this paper, we propose a signal-to-noise ratio (SNR) estimation algorithm based on preamble transmission. Through simulations of several channel environments, we prove that our proposed algorithm is more accurate than conventional algorithms.

1 INTRODUCTION

Adaptive modulation and coding (AMC), adaptive subcarrier allocation, and power allocation are used to increase the system's reliability and transmission rate. These techniques require feedback of the channel state information (CSI), which is based on the estimated SNR of the received signal. Therefore, many studies have been conducted to improve the system performance by designing a low complexity SNR estimation algorithm (Pauluzzi and Beaulieu, 2000); (Xu et al., 2005); (Jiao et al., 2008); (Boumard, 2003); (Ren et al., 2009); (Zivkovic and Mathar, 2009). Previously, conventional SNR estimation algorithms were based on the maximum likelihood (ML) or minimum mean squared error (MMSE) and required an estimation of the channel, which entails feedback delay and higher computational cost. Recently, some researchers such as Boumard, Ren and Milan proposed estimating the SNR based on preamble transmission without channel estimation. Our proposal consists of using the preamble principle to diminish the complexity and feedback delay and avoid channel estimation. Because the preamble is known by both sides of the transceiver, the new algorithm can accurately the follows. In section 2, we present the system model, and in section 3, we briefly explain the conventional SNR estimation algorithms proposed by Boumard, Ren, and Milan, as well as the new proposed SNR estimation algorithm. In section 4, we analyze and compare the simulated performance of each of the algorithms. Finally, in section 5, we present our conclusions.

2 SYSTEM MODEL

In this section, we explain the structure of the communication system. As shown in Figure 1, only two signals with two respective preambles are transmitted. The two transmission and two receiver antennas make up a 2×2 multiple-input multiple-output (MIMO)-orthogonal frequency division multiplexing (OFDM) system. At the receiver, the SNR is estimated after the received signal is changed from the time domain to the frequency domain using fast Fourier transform (FFT). The timing of the received signal is assumed to be perfectly synchronized.

2.1 Transmitter

Each antenna transmits an OFDM symbol, consisting of a sequence of a predetermined number (OFDM size) of binary phase shift keying (BPSK) or quadrature phase shift keying (QPSK) symbols. The preamble is thus composed of these two identical OFDM symbols. In Figure 1, the preamble is given by $C_i(k, n)$, where, $i = 1, 2$ represents the

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transmit antenna index, $k = 1, 2$ is the preamble index, and $n = 0, ..., N-1$ is the subcarrier index. For preamble transmission, we used a cyclic prefix (CP) of length $N/4$ as the guard interval.

2.2 Receiver

The received signal after FFT processing is described by equation (1):

$$Y_j(k,n) = \sum_{i=1}^{2} H_{ij}(k,n)C_i(k,n) + n_j(k,n) \qquad (1)$$

where $Y_j(k, j)$ *is* the signal received at the *j*th antenna, and $n_j(k, n)$ is the additive white Gaussian noise (AWGN) present at the input of the *j*th receive antenna. $H_{ij}(k, n)$ indicates the channel frequency response between the *i*th transmission antenna and the *j*th receiver antenna. It can be expressed according to equation (2),

$$H_{ij}(k,n) = \sum_{l=1}^{L} h_{l,ij}(kT_s)e^{-j\pi\frac{n\tau_{l,ij}}{NT_s}} \qquad (2)$$

where $h_{l,ij}(k, T_s)$ and $\tau_{l,ij}$ represent the *l*th path gain and delay, respectively, between the *i*th transmission and *j*th receiver antenna during the *k*th preamble. T_s is the OFDM preamble time plus CP, and L is the number of channel paths. In this paper, the channel is assumed to be constant during a frame period. Therefore, for simplicity, the time k is not taken into account for SNR estimation.

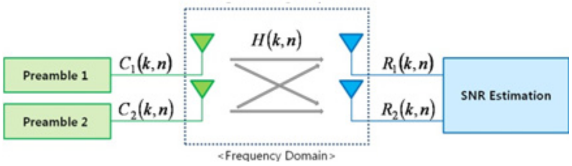

Figure 1: Block diagram of the preamble-based 2×2.

3 CONVENTIONAL SNR ESTIMATION ALGORITHMS

3.1 Boumard's SNR Estimation Algorithm

According to the Boumard algorithm, in a *2×2* MIMO-OFDM system, the channel varies slowly in both the frequency and time domains; with this assumption, two identical consecutive preambles are used to estimate the SNR (Boumard, 2003). The signal power is estimated as follows. First, we estimate $\hat{H}$ using equation (3), which is a function of the two received signals $Y(0, n)$ and $Y(1, n)$, and the transmitted preamble $C(n)$. Next, we calculate the average of the squares of the absolute values of $\hat{H}$ using equation (4). The noise power is estimated using equation (5), and finally, the SNR is estimated using equation (6). Unlike ML or MMSE-based SNR estimation, Boumard's algorithm does not require channel estimation, but large changes in the channel can lead to errors in the SNR estimate.

$$\hat{S}_{Bou} = \frac{1}{N}\sum_{n=0}^{N-1}\left|\hat{H}(n)\right|^2 \qquad (3)$$

$$\hat{H}(n) = \frac{C^*(n)}{2}\left(Y(0,n)+Y(1,n)\right) \qquad (4)$$

$$\hat{W}_{Bou} = \frac{1}{N}\sum_{n=1}^{N-1}\left|\begin{matrix} C(n-1)(Y(0,n)+Y(1,n)) \\ -C(n-1)(Y(0,n-1)+Y(1,n-1)) \end{matrix}\right|^2 \qquad (5)$$

$$\hat{\rho}_{av,Bou} = \frac{\hat{S}_{Bou}}{\hat{W}_{Bou}} \qquad (6)$$

3.2 Ren's SNR Estimation Algorithm

Ren's SNR estimation overcomes the weakness of Boumard's regarding frequency selective channels by using the same subcarrier in the noise power estimation [equation (7)] (Ren et al., 2009). The signal power is estimated by equation (8), where the estimated noise power is removed from the total received signal power. As in Boumard's algorithm, Ĥ is estimated by equation (3), and finally, we calculate the SNR with equation (9).

$$\hat{W}_{Ren} = \frac{4}{N}\sum_{n=0}^{N-1}\left\{\mathrm{Im}\left[\frac{Y(0,n)C^*(0,n)\hat{H}^*(n)}{\left|\hat{H}^*(n)\right|}\right]\right\}^2 \qquad (7)$$

$$\hat{S}_{Ren} = \frac{1}{N}\sum_{n=0}^{N-1}\left|Y(0,n)\right|^2 - \hat{W}_{Ren} \qquad (8)$$

$$\hat{\rho}_{av,Ren} = \frac{\hat{S}_{Ren}}{\hat{W}_{Ren}} \qquad (9)$$

3.3 Milan's SNR Estimation Algorithm

The preamble used in Milan's SNR estimation algorithm contains periodic identical parts in the time domain (Zivkovic and Mathar, 2009). Figure 2(a) shows the structure of the preamble in the time domain. N subcarriers are divided into Q identical parts. Figure 2(b) shows the preamble structure in the frequency domain. Q signal subcarriers appear periodically between the null subcarriers. Milan's algorithm uses these characteristics to estimate the SNR. After the received signal is FFT modulated (with an FFT size equal to the total preamble duration, i.e., 128), the signal power is contained in the Q signal subcarriers, and the noise power is contained in the null subcarriers of the received signal. As we can see in reference (Pauluzzi and Beaulieu, 2000), Milan's algorithm provides more accurate estimations by reducing the interval period; however, the preamble structure becomes more complicated. In our system, we transmit two equal OFDM symbols of size $N = 64$, which is the preamble length corresponding to Milan's algorithm for the case of N = 128 and $Q = 2$. However, in our algorithm we need an FFT size of only *64* at the receiver, whereas Milan's algorithm requires an FFT size of *128*.

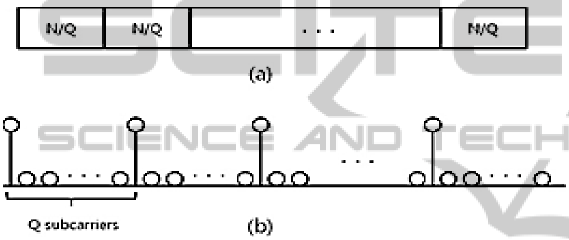

Figure 2: Preamble structure of Milan's algorithm. (a) Time domain, (b) frequency domain.

3.4 New SNR Estimation Algorithm

Figure 3 shows the structure of the transmission frame, including the preamble. Equation (10) is the new expression for estimating the SNR, where *Y(0, n)* and *Y(1, n)* represent the consecutive receive preambles after FFT.

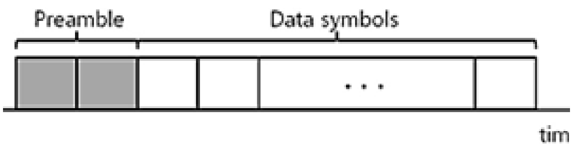

Figure 3: Transmit preamble structure in the new SNR estimation algorithm.

$$\rho_{av,New} = \frac{1}{\left(\frac{1}{N} \sum_{n=1}^{N} \left| Y(0,n) - Y(1,n) \right|^2 \right)} \tag{10}$$

According to equation (10), the signal power is considered to be the total power carried by the preambles, i.e., the noise power is calculated by the average of the square of the absolute values of the received preambles.

4 PERFORMANCE ANALYSIS OF THE PROPOSED AND CONVENTIONAL SNR ESTIMATION ALGORITHMS

In this section, we present the performance analysis of the proposed and conventional SNR estimation algorithms. Table I and Table II contain the simulation and channel parameters, respectively. The simulation parameters are based on IEEE Standard 802.11n; they include 20 MHz of bandwidth and MIMO-OFDM as the simulation platform. The SNR is estimated by considering only two consecutive preambles with the OFDM symbol size and BPSK or QPSK modulation. We performed simulations over three different channels: the Rayleigh flat fading channel, where the channel conditions change only slightly; Rayleigh selective fading channel A, where the maximum delay of the samples is shorter than the CP; and Rayleigh selective fading channel B, where the maximum delay of the samples is longer than the CP.

$$NMSE_{av} = \sum_{i=1}^{N_t} \left(\frac{\hat{\rho}_{av,i} - \rho_{av}}{\rho_{av}} \right)^2 \tag{11}$$

where N_t is the number of transmitted packets (25,000), $\hat{\rho}_{av,i}$ is the estimated SNR value corresponding to the received preamble from the *i*th package, and ρ_{av} represents the actual SNR value. Figure 4 compares the actual SNR values and those estimated by each algorithm over the Rayleigh flat fading channel. At low SNRs, the Ren algorithm has a higher SNR estimation error than the other algorithms, which return values almost identical to the actual SNR. Figure 5 shows the NMSE performance for each algorithm. We can verify that Boumard's and the new SNR algorithm provide the most accurate estimations, with NMSE values close to 0, followed by Milan and Ren. As mentioned in the description above, for Boumard's algorithm the channel is considered to be almost stationary. The performance results, confirm that the most suitable algorithms for these conditions are Boumard's and the new SNR estimation algorithm. Figure 6 compares the actual and estimated SNR values over Rayleigh selective fading channel A.

The estimation error of Boumard's algorithm increases for a selective channel. Figure 7 shows the NMSE performance on the same channel. For Boumard's algorithm, the NMSE increases with the SNR, whereas Milan's and Ren's algorithms maintain a constant NMSE value of about 0.3

starting at approximately 0 dB. The NMSE of the new algorithm is very close to 0, which means that for a frequency selective multi-path channel, the new algorithm provides the most reliable estimation of the real SNR value. Figure 8 and Figure 9 show the result of the same simulations over Rayleigh selective fading channel B, where the maximum delay is larger than the CP length, using four multiple paths. This channel environment is more difficult than channel A; therefore, each algorithm has a higher estimation error than in the previous simulation of channel A. In Figure 8, the values estimated by Boumard's algorithm are very far from the actual SNR values, whereas those estimated by the new algorithm, as the values estimated by Boumard's algorithm are very far from the actual SNR values, while those estimated by the new algorithm, as well as by those of Milan and Ren, remain very close to the actual value until approximately 26 dB. Furthermore, Figure 9 shows that until approximately 38 dB, the new algorithm has the lowest estimation error.

Table 1: Simulation parameters.

Parameters	Value
System bandwidth (BW)	20 MHz
1 OFDM symbol time	4 µs(3.2 µs: FFT length + 0.8 µs: CP length)
Number of data symbols per space stream(SS)	468
Number of subcarriers per preamble	64
Subcarrier spacing	312.5 KHz
MIMO	Layered 2×2
Noise	AWGN
FFT length	64 point
GI(CP) length	16 point
1 OFDM symbol samples	80
SNR estimation algorithm	Boumard, Milan, Ren, new
Preamble	2 OFDM symbols: 2 equal sequences of QPSK or BPSK symbols
Transmission packets	25000

Table 2: Channel parameters.

Channel	Delay path(samples)	Rayleigh power
Rayleigh selective fading channel A	3Path: [0 12 15]	[-1.92, -5.92, -9.92]
Rayleigh selective fading channel B	4Path: [0 12 15 18]	[-1.92, -5.92, -9.92, -12.92]
Rayleigh flat fading channel	No delay	-

5 CONCLUSIONS

In this paper, we proposed a new SNR estimation algorithm that is based on the use of a preamble and does not require channel estimation to make an accurate estimation of the SNR.

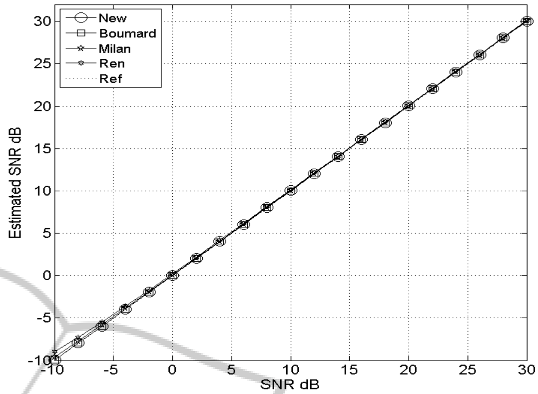

Figure 4: Actual and estimated SNR values over the Rayleigh flat fading channel.

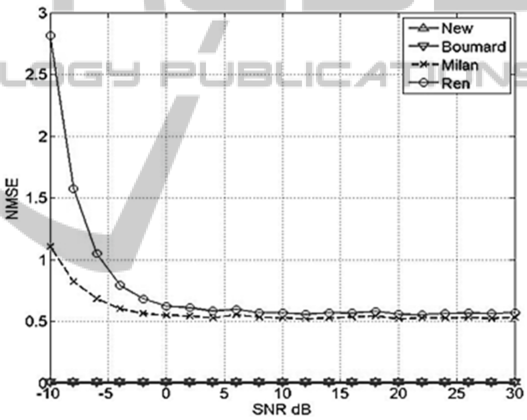

Figure 5: NMSE performance over Rayleigh flat fading.

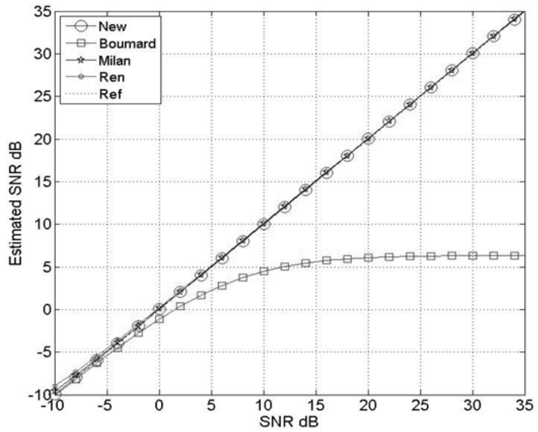

Figure 6: Actual and estimated SNR values over Rayleigh selective fading channel A.

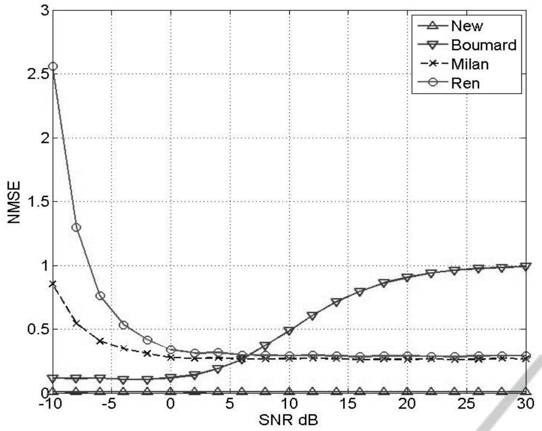

Figure 7: NMSE performance over Rayleigh selective fading channel A.

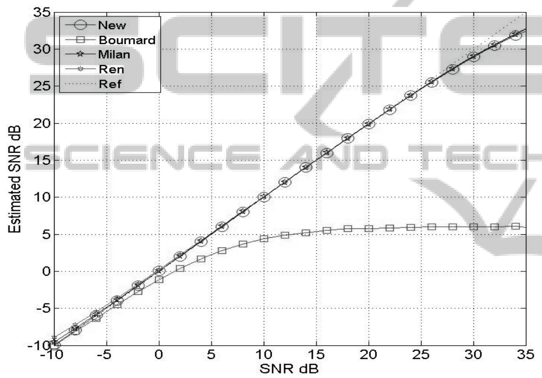

Figure 8: Actual and estimated SNR values over Rayleigh selective fading channel B.

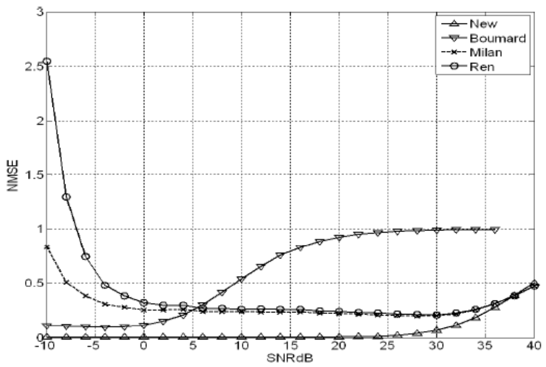

Figure 9: NMSE performance over Rayleigh selective fading channel B.

In our algorithm, the signal power is considered to be the entire sequence of two preambles with OFDM size and composed of BPSK or QPSK symbols; therefore, we consider the signal power to be 1. The relative noise power is calculated by the square of the absolute value of the two received preambles. By dividing the signal between the noise power, we obtain the SNR estimation. Simulations performed in several channels prove that the new proposed algorithm produces the lowest estimation error.

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