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Channel Estimation on the (EW) RLS Algorithm Model of MIMO OFDM in Wireless Communication

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Abstract. This paper study the channel estimation based on the exponentially weighted (EW) RLS algorithm. The advantages of the proposed estimator arise from its implementation in the time-domain, whereas fewer channel parameters are required to be estimated compared with the frequency-domain channel coefficients. In addition, the matrix inversion operation required in LS and LMMSE estimators is avoided here by recursively updating the channel estimates. Therefore, the computational complexity is highly reduced compared to frequency-domain based channel estimation. Furthermore, the proposed estimator has good tracking capability due to exploiting the time correlation between the path gains. This paper provides analysis, evaluation and computer simulations in MATLAB. The performance is evaluated in terms of the MSE of the channel estimate and BER for different Doppler frequencies (correspond to different mobility speeds) and Monte Carlo simulations are performed and the MSE and BER performance versus SNR are obtained by averaging over 10000 channel realization. For comparisons, the BER performance is also presented for perfectly known channel at the receiver. In all the simulations, perfect synchronization between the transmitter and the receiver is assumed.

1 Introduction

OFDM is a multi-carrier modulation technique which is used to transmit high data rate data stream through wireless medium. MIMO-OFDM is a new wireless broadband technology which has great robustness against multipath fading and capability of high rate transmission and other channel impairments. MIMO-OFDM also has significant potential performance enhancements over existing wireless technology by concurrently exploiting the space, time and frequency domain. Channel estimation technique is introduced to improve accuracy of the received signal even though it is a challenging problem in any communication system especially when the channel is time-varying. These authors [1] proposed RLS channel estimator with improved decision-directed algorithm based on training sequences to eliminate interference. Performance of RLS channel estimation algorithm proved its efficiency in [2] by increasing the number of receive antenna even though RLS has high complexity. Due to the interference occur, original symbol that had been distorted during propagation need to be recovered back at the receiver [3]. A few authors [4] [5] also used different type of algorithm to combat interference and improve channel estimation accuracy. This part of the paper addresses the problem of channel estimation and tracking in MIMO OFDM systems based on adaptive filtering. The channel is assumed to be slow to moderate time-variant frequency-selective fading channel. The frequency selectivity of the channel arises as a result of relatively high transmission rates, where the transmission bandwidth exceeds the coherence bandwidth of the channel, thereby leading to significant changes of the channel within the band of the transmitted signal. The time-variant nature of the channel is considered to be significant within a frame of OFDM symbols. Hence, the need for channel tracking arises in order for the equalization to be effective.

2 Methodology

Adaptive channel estimation and tracking scheme for MIMO OFDM systems based on DD EW-RLS algorithm with time-domain training is presented. Channel estimation and then tracking are performed in time domain while channel equalization is implemented in frequency domain. The channel estimates are updated recursively upon receiving new training sequences. In general, we assume that training sequences of equal length n are employed, where n may take any value in the range $L \leq n \leq K - 1$. Further, assume that the channel remains fixed during the observation interval $0 \leq i \leq n$, where i denotes the recursion index. The estimation process is performed by recursively adjusting the time-varying tap-weight vector $\widehat{h_n}$ of the transversal filter according to an instantaneous a *posteriori* estimation error $e(i)$, defined as the difference between the noisy received signal y_q (i) and its estimate $\widehat{y_q}(i)$ given by the adaptive filter output. Figure 1, illustrates how an adaptive filter is used to estimate unknown channel. The filter adaptation proceeds on a sample-by-sample basis, while the time update of the estimated channel proceeds on a block-by-block basis. Since the CIRs among the different transmit-receive antenna pairs are independent, channel estimation at each receive antenna is carried out independently.

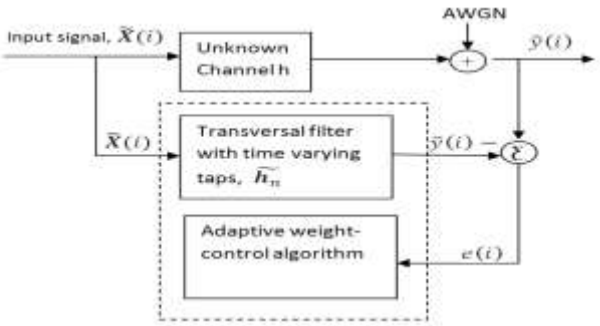

Figure. 1. Illustration of adaptive filter modelling of unknown channel.

Channel estimation and tracking based on adaptive algorithms is also considered. Specifically, the exponentially weighted recursive least squares (EW-RLS) and normalized least-mean square (NLMS) algorithms are used, jointly with decision-directed (DD) technique, for building the proposed estimators. First, the channel is estimated in time-domain followed by zero forcing equalization in frequency-domain. Then, the equalized data symbols are exploited as training sequences to train the estimator to blindly track the time-variations of the channel. Two estimation methods are proposed. In the first method, the CIRs are estimated in TD through exploiting preamble sequences inserted in TD. In the other method, the CIRs are obtained by substituting for the channel frequency responses (CFRs) by their corresponding representations as a FFT matrix multiplied by the CIRs. In such method, the pilot-symbols are inserted in FD on some pre-defined subcarriers. Inserting the training sequences in TD has the advantage of avoiding the problem of peak-to-average power ratio (PAPR) of the training sequences. The training symbols either as preambles or pilots are periodically transmitted to update the channel estimates.

By using typical baseband MIMO OFDM system, training sequences are demultiplexed in time –domain at the receiver. After removing guard interval (GI), the time domain K×1 received signal at the qth antenna during transmitting the mth OFDM symbol can be written as

$$\tilde{y}_q(m) = \sum_{p=1}^{M_t} \tilde{X}_p(m)\, h_{pq}(m) + v_q(m) \quad (1)$$

Where $\mathbf{X}\tilde{}_p(m)$ is N x L Toeplitz matrix contains delayed versions of the input data sent from the pth transmit antenna. $\mathbf{h}_{pq}$ is the channel impulse response between the pth transmit and the qth receive antennas while $\mathbf{v}_q(m)$ is a K x 1 vector representing additive white Gaussian noise (AWGN) at the qth receive antenna with complex elements.

Data vectors are demodulated after assuming guard interval is larger than length of MIMO subchannels. ISI will not occur between OFDM symbols and received signals of the different subcarriers can be viewed as independent of each other. Then, frequency-domain received signal at the qth antenna over kth tone at the time m, $Y_q(m,k)$ can be expressed as

$$Y_q(m,k) = \sum_{p=1}^{M_t} H_{pq}(m,k) X_p(m,k) + V_q(m,k) \quad (2)$$

where $X_p(m,k)$, $H_{pq}(m,k)$ and $V_q(m,k)$ denote the kth data sample of the transmitted OFDM symbol from the pth antenna, the channel coefficient of the kth tone between the pth transmit and the qth receive antennas, and the noise at the qth receive antenna on the kth tone, respectively.

3 Model System Settings

3.1 Initial Conditions

In RLS algorithm, there are two variables involved in the recursion that need initialization, namely, the channel under estimation $\hat{\mathbf{h}}_{(-1),q}$ and the inverse of the autocorrelation of the inputs $\mathbf{\Psi}(-1)$. In our simulations, the initial state conditions of these parameters are set as in Table 1, since our knowledge of these parameters is indistinct, a very high covariance matrix of $\mathbf{\Psi}(-1)$ is to be expected, and thus a high value to $\boldsymbol{\delta}$ is assigned.

Table 1. The initial conditions of the RLS algorithm parameters.

The parameter	Initial state
Channel under estimation , $\hat{\mathbf{h}}_{(-1),q}$	$0_{(M_t L\times1)}$
Inverse of the autocorrelation matrices of the inputs, $\mathbf{\Psi}(-1)$	$\delta^{-1}\mathbf{I}_{M_t L}$
Regulation parameter (small positive constant),$\boldsymbol{\delta}$	1×10^{-6}

3.2 Simulation Parameters

We consider 2-transmit and 2-receive antennas (2×2) MIMO OFDM system, which can be straightforward extended to nay number of transmit and receive antennas. The simulated system parameters are given in Table 2. In the simulations, a forgetting factor of $\lambda = 0.995$ is used.

Table 2. System and Channel Parameters

Parameter	Value
Channel bandwidth (BW)	20MHz
Sampling frequency (f_s)	20MHz
FFT size (N_{FFT})	128
Number of subcarriers (K)	128

Subcarrier spacing (Δf)	147.06 kHz
Cyclic prefix length (N_{cp})	8 samples
Modulation type	QPSK
OFDM symbol duration (T_s)	6.8μs

4 Channel Estimation in Time-Domain(TD)

Training Schemes Design

Training sequences with constant magnitude are inserted in time-domain (i.e., after the IFFT modulators), thereby the problem of peak-to-average power ratio (PAPR) of the training sequences is avoided. Two training schemes are investigated:

Schemes I: The training sequences from the different antennas are arranged in a sequential manner (i.e., orthogonal in time) in a block or more, where each block has a length equivalent to the length of one OFDM symbol. The criterion for choosing the number of blocks required to transmit the training sequences depends on the number of subcarriers K, transmit antennas M_t, maximum channel length L, and the guard interval N_g. Assume that $N_g \geq L$, the inequality that shows the relation between these variables may be written as

$$K + N_g \geq M_t (L_{ts} + N_g) \quad (3)$$

$$L_{ts} \leq \frac{K + N_g(1 - M_t)}{M_t} \quad (4)$$

Where L_{ts} denotes the length of a training sequence.

Schemes II: The training sequences are simultaneously transmitted from the different antennas, where a number of OFDM symbols equal to the number of transmit antennas is used for training.

5 Results and Analysis

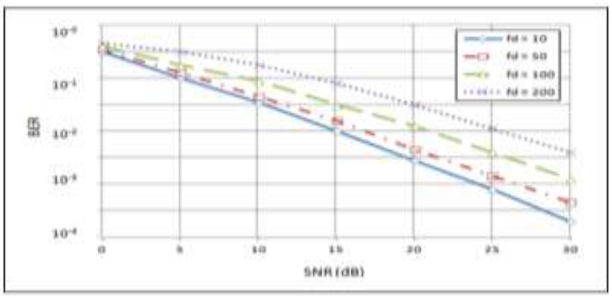

Figure. 2. MSE of channel estimates with time-orthogonal training sequences (Scheme I)

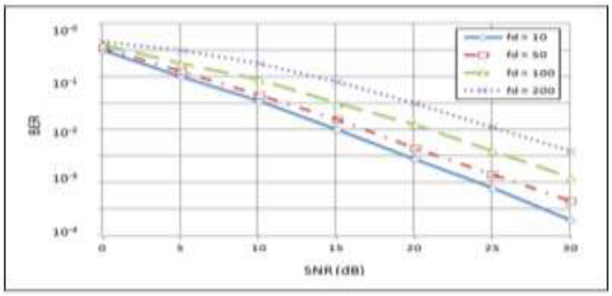

Figure. 3. The BER performance vs. SNR, with time-orthogonal transmitted training sequences (Scheme I)

Simultaneously Transmitted Training Sequences

The training sequences are simultaneously transmitted from the different antennas, where a number of OFDM symbols equal to the number of transmit antennas is needed for training. We refer to this training scenario as scheme II. For this case, the MSE of the channel estimates and the BER performance versus the SNR are shown in Figure 2 and 3, respectively.

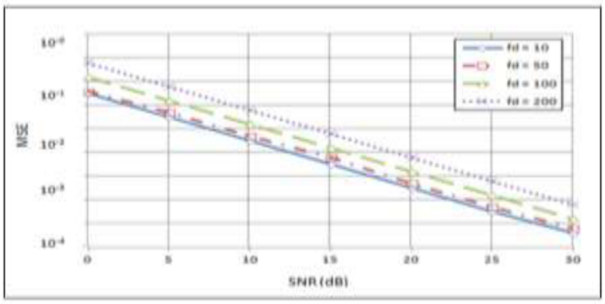

Figure. 4. MSE of channel estimates with simultaneously transmitted training sequences (Scheme II)

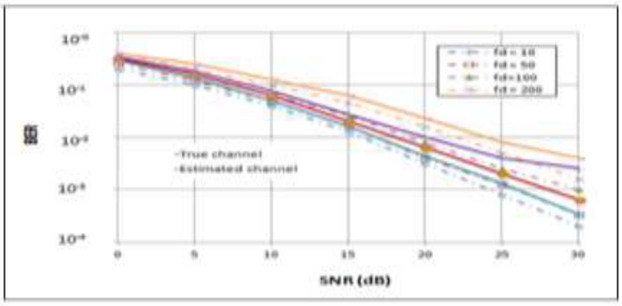

Figure. 5. The BER performance vs. SNR, with simultaneously transmitted training sequences (Scheme II)

From Figure 1 and 2, it can be seen that the proposed channel estimator with training scheme I has much better estimation performance than that with training scheme II. Quantitatively, for example, at a MSE of 10^{-3} a gain difference of 11.5 dB in favoring of training scheme I over training scheme II is obtained. It can also be noticed from the Figure 4 that the BER performance curves obtained with training scheme I are very close to those with perfect channel knowledge at the receiver. On the contrary, Figure 5 shows that the BER performance with training scheme II suffers some degradation due to the enhanced noise at the receiver. For example, to achieve a BER of 10^{-2} at f_d=100Hz, and increase in the SNR of about 2dB is required over that when training scheme I is used.

Channel Estimation in Frequency-domain

In case of the channel estimation is carried out in FD, pilot-symbols are multiplexed with the data symbols in each OFDM symbol where each eight subcarrier is used for training. The MSE of the channel estimates and the BER performances are shown in Figure 6 and 7, respectively.

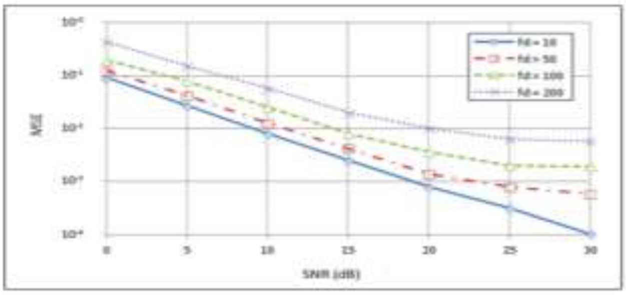

Figure. 6. MSE of channel estimates of the EW-RLS estimator in FD

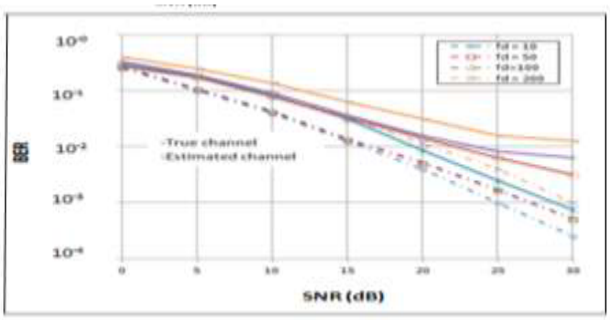

Figure. 7. The BER performance vs SNR, with EW-RLS channel estimation in FD

Comparing the result in Figure 6 and 7 with their corresponding Figure 2 and 3, obtained for EW-RLS channel estimator in TD, it can be noticed that at the lower SNR range and lower Doppler frequencies, more of 10dB SNR is required for the FD estimator to get the same MSE of the TD estimator. However, at the higher SNR and higher Doppler frequencies, an error floor has appeared in case of FD-based channel estimation, the situation which is not occurred in case of Td-based channel estimation. Similarly, it can be observed that the BER performance curves obtained for different Doppler frequencies with the TD channel estimation are very close to the ideal, while severe degradation in the BER performance has occurred when FD channel estimation is performed.

6 Conclusion

Simulation results show that the proposed estimator performance with the time-orthogonal training sequences outperforms that with simultaneously transmitted training sequences. In addition, one OFDM symbol duration is only required for training in case of time-orthogonal training sequences compared to two OFDM symbol durations in case of simultaneously transmitted training sequences. Simulation results also proved that the estimator performance, in terms of MSE and system BER, in TD is superior over that obtained in FD, for different Doppler frequencies. Channel estimation in time-domain is attractive over its counterpart in frequency-domain due to its lower computational complexity, accuracy, and effective channel impulse response tracking especially when the channel is time-varying.

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