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Pilot sharing method for uplink OFDMA channel estimation

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Abstract: This paper proposes an orthogonal pilot-aided channel estimation scheme for uplink (UL) orthogonal frequency division multiple access (OFDMA) systems. In the proposed method, the users utilizing adjacent UL subchannels in the frequency domain share some common pilot subcarriers by using orthogonal pilot patterns. In this way, each user can effectively use more pilot subcarriers and can improve the quality of channel estimation, especially for the data subcarriers located near the edges of a multiple access (MA) user subchannel in the frequency domain, and can offer a better bit error rate than user dedicated pilot allocations.

Keywords: channel estimation, uplink OFDMA, pilot
Classification: Science and engineering for electronics

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1 Introduction

OFDMA has been adopted for the uplink MA scheme for next-generation mobile communication systems such as IEEE 802.16e/m and 3GPP2 UMB systems. In the downlink OFDMA, each user can share all the transmitted pilots and any kind of channel estimation methods for orthogonal frequency division multiplexing (OFDM) [1, 2, 3, 4] can be directly applied without modification. However, in the uplink OFDMA, channel estimation for each UL user should be performed by using the pilots dedicated to each user. If the subchannels allocated to an UL user are distributed over an entire bandwidth, the model-based channel estimation method can be used [5]; however, this method cannot be applied to chunk-type OFDMA subchannels and it requires significant pilot overhead for large delay-spread channels. For chunk-type OFDMA resources, the channel estimation method that is based on the overall time-domain channel estimation of all UL users is proposed [6]. However, if some of the subchannels are not allocated to any user, this method cannot be applied and still requires significant pilot overhead.

To solve the channel estimation problem under the limited number of pilots within the allocated subchannel, only the interpolation/extrapolation-based channel estimation methods [2, 3] can be applied and they provide reasonable channel estimation performance; however, if there are no pilots at the edges of the subchannels, the channel estimation error is severely increased for the data subcarriers in the edges due to imperfect extrapolation. To improve the channel estimation at the edges, this paper proposes a pilot sharing method in which the MA users can share some of the pilot subcarriers by using the orthogonal pilot signals over two successive OFDM symbols. The orthogonality of pilot signals can cancel the mutual interference from the other user to the desired user sharing the same pilot subcarrier. By employing the proposed pilot sharing method, each user can utilize the additional pilots outside the assigned subchannel for interpolation, and therefore the extrapolation error for the subcarriers at the edge of the subchannel can be significantly reduced. Computer simulation results demonstrate that the proposed pilot sharing method can significantly improve the channel estimation performance without increasing the number of total pilot carriers.

2 Proposed channel estimation for uplink OFDMA systems

2.1 Problem description

Fig. 1 (a) shows a pilot subcarrier allocation for an UL OFDMA system with a conventional pilot pattern without pilot sharing. Each subchannel consists of N_pL contiguous subcarriers; N_p pilots are equally spaced with a pilot spacing of L subcarriers. If there are M subchannels, the the total number of used

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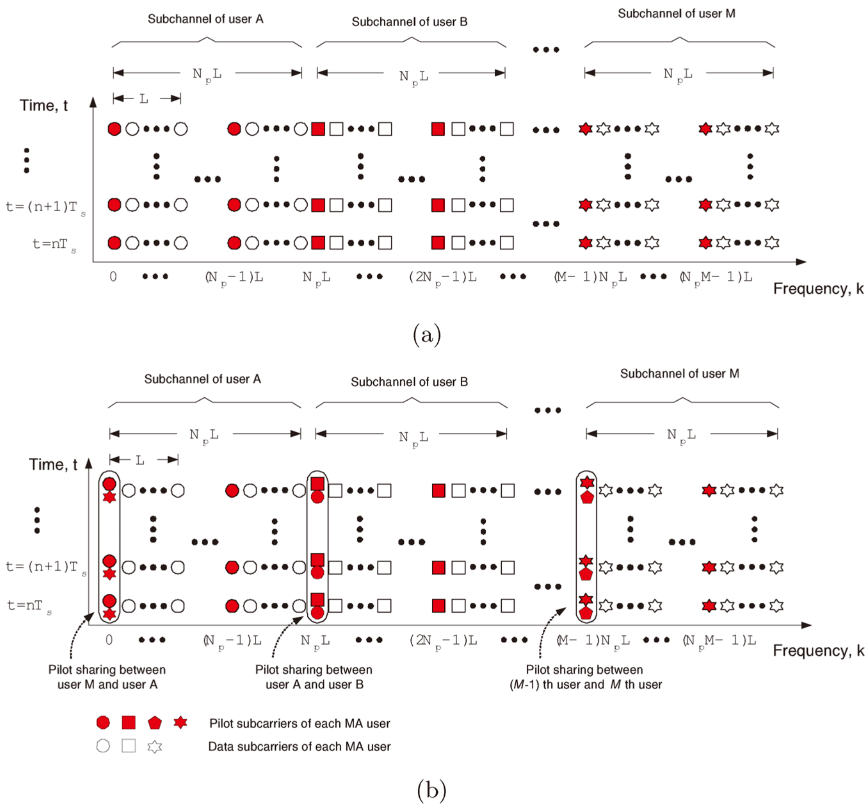

Fig. 1. (a) A pilot subcarrier allocation for an uplink OFDMA system without pilot sharing. (b) A proposed pilot subcarrier allocation with pilot sharing.

subcarriers is N_pLM. In order to estimate channel parameters without error flow for downlink OFDMA, it requires more than L_{max} pilots [3], where L_{max} is the maximum number of multipaths in the time domain. When more than one user shares the OFDMA subchannels, the number of pilots per user should also be larger than or equal to L_{max} and the pilots should be allocated across the entire bandwidth, because each individual UL user has the same channel characteristic as the single user OFDM channel. However, the total number of pilots is limited for UL OFDMA, and the number of pilots assigned to each user is much less than L_{max}; pilots are assigned only inside the assigned subchannels. Therefore, the BS obtains the channel estimate for each user with the pilot subcarriers in an assigned subchannel, and it obtains the channel estimate for the non-pilot subcarriers by any kind of interpolation and extrapolation method. If the pilot pattern in Fig. 1 (a) is used, the channel estimation error can be significantly increased for the data subcarriers located at the outside of the pilot subcarriers due to the extrapolation without any reference signal outside of the subchannel.

A variation in the above equally spaced pilot subcarrier allocation scheme can be considered to reduce the negative effects of extrapolation. For example, a larger number of pilot subcarriers can be allocated at the edge than at the middle position. However, the frequency separation between the adjacent pilot subcarriers in the middle position will be increased for a given number

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of pilots and this increases the channel estimation error in the middle of the subchannel when compared to the pilot pattern of Fig. 1 (a). Therefore, a new pilot allocation scheme without increasing the pilot spacing is desirable.

2.2 Proposed pilot sharing method

Fig. 1 (b) shows an example of the proposed pilot sharing scheme in which two users assigned to adjacent subchannels in the frequency domain share pilot subcarriers. In the figure, the subcarrier indices for shared pilots are $k = (m-1)N_pL, (m = 1, \cdots, M)$. By sharing some pilot carriers in the edge of the subchannel, each user can utilize additional pilot carriers without decreasing the number of data subcarriers. If all pilot carriers are assigned to shared pilots, at most $2N_p$ pilots can be utilized for each subchannel. If some of the subchannels are not utilized or more than two adjacent sub-bands are assigned to a single user, the shared-pilots can be occupied by a single user.

For example, if we assume that two adjacent subchannels are assigned to users A and B, then the received signal at the k^{th} subcarrier, which is shared by users A and B for the n^{th} and $(n+1)^{th}$ OFDM symbol time intervals, can be written as

$$Y_n(k) = H_n^A(k)X_n^A(k) + H_n^B(k)X_n^B(k) + W_n(k) \tag{1}$$

$$Y_{n+1}(k) = H_{n+1}^A(k)X_{n+1}^A(k) + H_{n+1}^B(k)X_{n+1}^B(k) + W_{n+1}(k) \tag{2}$$

where $X_n^q(k)$ is the pilot signal of the kth subcarrier in the n^{th} OFDM symbol interval for the user q; $H_n^q(k)$ is the frequency domain channel parameter for the k^{th} subcarrier in the n^{th} OFDM symbol for user q; $W_n(k)$ is the AWGN at the k^{th} subcarrier in the nth OFDM symbol interval; and $Y_n(k)$ is the received signal at the k^{th} subcarrier in the n^{th} OFDM symbol interval. If we assume block fading channels in which channel parameters are not changed for the two contiguous OFDM symbol intervals, the above equations can be written as

$$\begin{bmatrix} Y_n(k) \\ Y_{n+1}(k) \end{bmatrix} = \begin{bmatrix} X_n^A(k) & X_n^B(k) \\ X_{n+1}^A(k) & X_{n+1}^B(k) \end{bmatrix} \begin{bmatrix} H_n^A(k) \\ H_n^B(k) \end{bmatrix} + \begin{bmatrix} W_n(k) \\ W_{n+1}(k) \end{bmatrix}. \tag{3}$$

Using a vector notation, the above equation can be written as

$$\mathbf{Y}(k) = \mathbf{X}(k)\mathbf{H}(k) + \mathbf{W}(k). \tag{4}$$

Suppose that $\mathbf{X}(k)$ is designed so that its inverse exists, then the maximum likelihood estimator (MLE) $\hat{\mathbf{H}}(k)_{ML}$ can be derived as

$$\hat{\mathbf{H}}(k)_{ML} = \mathbf{X}(k)^{-1}\mathbf{Y}(k). \tag{5}$$

The mean square error (MSE) of the MLE in the form of (5) can be written as

$$MSE(k) = \sigma^2 \cdot tr\{(\mathbf{X}(k)^H\mathbf{X}(k))^{-1}\} \tag{6}$$

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where σ^2 is the noise variance and $tr(\cdot)$ is the trace of a matrix [7]. To achieve the minimum MSE, it is necessary to select $\mathbf{X}(k)$ so that it minimizes $tr\{(\mathbf{X}(k)^H\mathbf{X}(k))^{-1}\}$, and it can be shown that $tr\{(\mathbf{X}(k)^H\mathbf{X}(k))^{-1}\}$ is minimized when $\mathbf{X}(k)$ satisfies the following relationship [8]:

$$\mathbf{X}(k)\mathbf{X}(k)^H = \mathbf{X}(k)^H\mathbf{X}(k) = \alpha I \tag{7}$$

which implies that $\mathbf{X}(k)$ should be an orthogonal (unitary) matrix in a real (complex) field. The examples of $\mathbf{X}(k)$ that satisfies (7) are a 2×2 identity matrix and a 2×2 Hadamard martix.

3 Simulation results

Uncoded bit-error-rate (BER) performance of the proposed pilot sharing scheme and the conventional pilot pattern without pilot sharing, as shown in Fig. 1 are compared in Fig. 2. The indices of pilot subcarriers for the proposed pilot-shared pattern are selected as $k = (p-1)L, (p = 1, 2, \cdots, MN_p)$, and the indices of pilot subcarriers for the conventional pilot pattern are selected as $k = (p-1)L + L/2, (p = 1, 2, \cdots, MN_p)$ to minimize the bad effect of extrapolation. The MMSE channel estimator [3] is used to obtain the channel estimates for data subcarriers, and a 2×2 Hadamard matrix is used for shared pilot signals according to the proposed method. The other simulation parameters are summarized as follows: carrier frequency $f_c = 3\,\text{GHz}$; sampling rate $f_s = 4\,\text{MHz}$; QPSK modulation for data subcarriers; 128 subcarriers are divided into four subchannels ($M = 4$) and each subchannel is assigned to different user; each subchannel has four pilot subcarriers ($N_p = 4$)

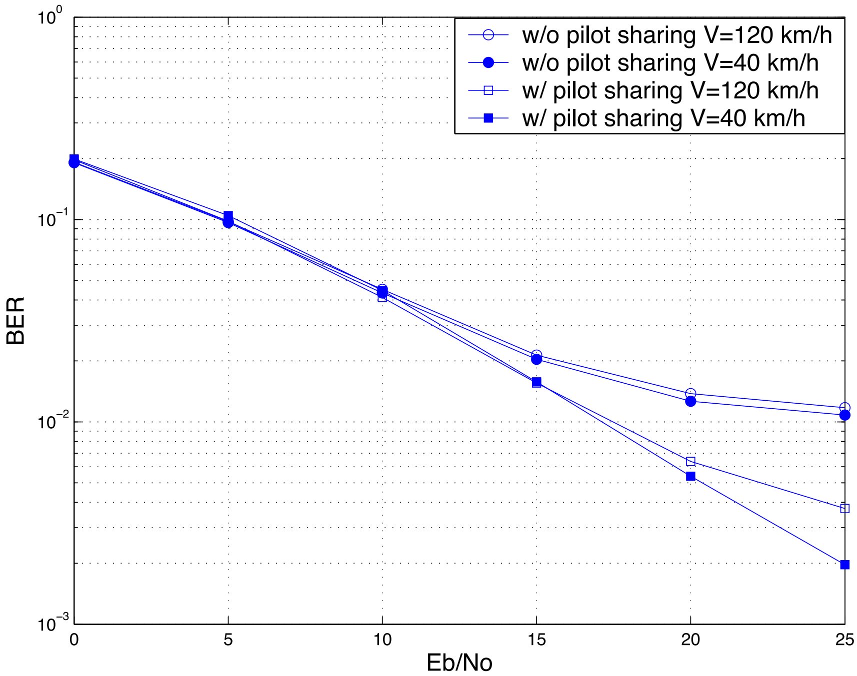

Fig. 2. BER performance comparison between no pilot sharing scheme and the proposed pilot sharing scheme.

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and $L = 8$; frequency selective Rayleigh fading channels with exponentially decaying delay profile with $L_{max} = 12$ and mobile speeds of 40 km/h and 120 km/h are tested.

For the proposed method, the pilots at the boundary of the subchannels ($k = 0, 32, 64, 96$) are used for shared pilots, and therefore, each user can utilize one additional pilot outside of the allocated subchannel and five pilots in total. For fair comparison, it is assumed that the proposed channel estimator and the other estimator have the same number of pilots, and the total power consumed by all the pilot subcarriers for the proposed pilot sharing is the same as that of the scheme without pilot sharing. It means that the energy of the pilots according to the proposed pilot sharing is only 4/5 of the energy of the pilots without pilot sharing. The proposed channel estimator with the pilot sharing shows a significant improvement over the channel estimation scheme without the pilot sharing, as expected. For example, at 10^{-2} uncoded BER, the proposed channel estimation scheme can provide more than 7.5 dB gain over the conventional pilot patterns without pilot sharing. The proposed pilots with pilot sharing are required to maintain constant channel parameters for two adjacent OFDM symbols, and therefore, the proposed channel estimation with pilot sharing is more sensitive to the mobile speed than the conventional channel estimation without pilot sharing, however the proposed pilot patterns still show better performance in a high speed mobile environments. The additional computation to use the proposed scheme is insignificant because the size of matrix $\mathbf{X}(k)$ for the MLE computation in (5) is only 2×2, and the inverse of a Hadamard matrix is the same as the original matrix.

4 Conclusion

An orthogonal pilot-aided channel estimator was proposed for an uplink OFDMA system. The unique difference in the proposed scheme from the existing channel estimators is that the proposed scheme introduces some common pilot subcarriers and lets the adjacent MA users share them. Thus, the proposed scheme could increase the estimation accuracy for the data subcarriers near the edges and could improve BER significantly over the channel estimation schemes without the pilot sharing method in the severe frequency selective channels.

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