Dynamic Pilot Arrangement Scheme in Wireless OFDM Systems

Chia-Chang Hu and Hong-Da Shih
Department of Communications Engineering,
National Chung Cheng University,
168, University Rd., Min-Hsiung, Chia-Yi 621 Taiwan

Abstract— **An adaptive pilot-symbol assignment scheme is proposed for interpolation-based channel estimation in wireless orthogonal frequency division multiplexing (OFDM) communication systems. The channel transfer functions of data tones are interpolated by the piecewise-linear and the second-order polynomial interpolation methods due to their inherent simplicity. Simulations are conducted to demonstrate system performance and bandwidth (BW) superiority. A comparative evaluation of the proposed dynamic pilot scheme with conventional fixed pilot-symbol channel estimation schemes is performed as well.**

I. INTRODUCTION

Orthogonal frequency division multiplexing (OFDM) technique has received considerable interest in wireless communications over the past few years due to its high-bit-rate transmission with superior bandwidth (BW) efficiency and its immunity to multipath fading. These features have motivated the adoption of OFDM as a standard for wireless LAN (IEEE 802.11a/g), digital audio broadcasting (DAB), digital video broadcasting (DVB) and so on.

In OFDM-based systems, pilot-assisted schemes are commonly employed for channel estimation and tracking in fast fading channels. In particular, the task of the channel estimation in a pilot-aided OFDM system has been widely investigated based on the maximum likelihood estimator (MLE) [1] and the minimum mean-square error estimator (MMSEE) [2], [3], [4]. The channel estimation using the MLE obviates the necessity of the information of either the channel statistics or the operating signal-to-noise ratio (SNR). An adaptive MMSE channel estimation scheme for block-type pilots in an OFDM system is proposed in [3]. Additionally, the two-dimensional optimum Wiener filtering for pilot-aided OFDM channel estimation is developed in [5]. This sort of the MMSE-based estimator with the use of the SNR and the channel status information (CSI) is capable to produce more precise channel estimation than the MLE. However, it is well known that the computational costs for both estimators are very expensive and thus lead to a limited usage in practice. In this paper, an adaptive time-varying pilot-symbol assignment scheme is developed for wireless OFDM interpolation-based communication systems. The proposed pilot-symbol arrangement algorithm accomplishes substantial improvement on BW efficiency and computational load simultaneously without affecting system bit error rate (BER) performance and dynamic convergence/tracking capability in channel estimation.

II. OFDM Signal Model

An OFDM system using N subcarriers is considered for the transmission of parallel data symbols at the transmitter. For channel estimation, a total of N_p comb-type pilots are uniformly inserted into the transmitted OFDM signal at known locations $\{i_n : 1 \leq n \leq N_p\}$. At the receiver, the signal of the lth OFDM block at the nth subcarrier can be written as

$$Y(l,n) = X(l,n)H(l,n) + W(l,n), \tag{1}$$

where $Y(l,n)$, $X(l,n)$, $H(l,n)$, and $W(l,n)$ in (1) represent the received data, the transmitted data, the frequency-domain (FD) channel response, and the zero-mean white Gaussian noise with variance σ_W^2, respectively.

III. ADAPTIVE PILOT-ASSIGNMENT OFDM

A. FD Channel Response Estimation

In this paper, the true channel impulse response is assumed to be unavailable, the receiver needs to derive the channel response estimate to recover the transmitted data symbol. The task of the channel estimation at pilot subcarriers in an OFDM-based system is performed in frequency domain and thus enables to be fulfilled efficiently. The interpolation-based algorithms are subsequently applied to determine the channel at unknown subcarriers due to the characteristic of continuity of the frequency channel response.

In the linear interpolation estimation, two consecutive FD pilot channel responses are employed to calculate the FD channel response located in between the pilots. The channel estimation at the (i_n+S)th subcarrier performed by the linear interpolation is given by

$$\hat{H}(l, i_n + S) = (1-\kappa)\hat{H}_p(l, i_n) + \kappa\hat{H}_p(l, i_{n+1}), \tag{2}$$

where $\hat{H}(l,n)$ stands for an estimate of $H(l,n)$, L is the interval of pilot subcarriers (i.e., $i_{n+1} - i_n = L$, $n \in [1, N_p]$), the integer $S \in [0, L-1]$ denotes the interval to the pilot subcarrier i_n, the scalar κ equals to S/L, and the estimated pilot channel response $\hat{H}_p(l, i_n)$ in (2) is recovered by the least squares (LS) estimation [6], given by

$$\hat{H}_p(l, i_n) = \lambda\hat{H}_p(l-1, i_n) + (1-\lambda)\frac{Y_p(l, i_n)}{X_p(l, i_n)}, \tag{3}$$

where λ is a forgetting factor $(0 < \lambda < 1)$ that controls the effective "memory" of the iterative process in (3). $Y_p(l, i_n)$ and $X_p(l, i_n)$ in (3) denote, respectively, the received pilot signal and the transmitted pilot signal.

The second-order polynomial interpolation technique is known to interpolate better than the linear interpolation method [7]. The channel estimated by the second-order interpolation algorithm is given by

$$\hat{H}(l, i_n + S) = a\hat{H}_p(l, i_{n-1}) + b\hat{H}_p(l, i_n) + c\hat{H}_p(l, i_{n+1}), \tag{4}$$

where the scalars $a = \kappa(\kappa-1)/2$, $b = -(\kappa-1)(\kappa+1)$, and $c = \kappa(\kappa+1)/2$.

B. Adjustable Pilot-Symbol Assignment Scheme

In principle, the use of a dense pilot mode (i.e., a smaller pilot spacing L) in an OFDM system usually leads to a better BER performance, but results in a heavier complexity burden. The opposite phenomena occur when a sparse pilot-symbol scheme is utilized. To overcome this problem, the decision on the variable number of OFDM pilots can be made by a trade-off between BER performance and computational complexity. Hence, the simple linear interpolation method is applied once more to determine the number of pilots dynamically for the successive OFDM block based on the "dB" values of the BER performance. The linear interpolation algorithm is defined by the equations, given as follows:

$$\overline{L}(l) = \begin{cases} L_{\mathrm{L}}, & \text{if} \quad \mathrm{BER}(l) < \mathrm{BER}_{\mathrm{L}}, \\ L_{\mathrm{L}} + \frac{(\mathrm{BER}(l) - \mathrm{BER}_{\mathrm{L}})}{(\mathrm{BER}_{\mathrm{H}} - \mathrm{BER}_{\mathrm{L}})}(L_{\mathrm{H}} - L_{\mathrm{L}}), & \text{if } ow \\ L_{\mathrm{H}}, & \text{if} \quad \mathrm{BER}(l) \geq \mathrm{BER}_{\mathrm{H}}, \end{cases} \tag{5}$$

where $\mathrm{BER}(l)$ denotes the BER achieved at the lth OFDM block, and $\mathrm{BER_L}$ and $\mathrm{BER_H}$ are the selected lower and upper values of $\mathrm{BER}(l)$, and L_L and L_H denote the pre-determined lower and upper bounds used for $L(l)$, respectively. When the value of $\mathrm{BER}(l)$ is fallen above (under) the upper (lower) bound, $\overline{L}(l)$ is set to a fixed pilot-spacing scale. Because $\overline{L}(l)$ is not necessary an exact pilot-spacing scale, the equation is required to compute the actual $L(l)$ as follows:

$$L(l) = \text{round}\left[\overline{L}(l)\right], \tag{6}$$

where round$[\cdot]$ indicates rounding to the nearest pilot-spacing scale.

IV. NUMERICAL RESULTS

The system and channel parameters of the pilot-aided OFDM system are summarized in Tables I and II, respectively. Here, the 802.16a SUI-4 [8] is employed for the settings of the channel parameters. Other parameters of $L_\mathrm{L} = 6$, $L_\mathrm{H} = 30$, $\mathrm{BER_L} = 0.2$ (i.e., -7dB) and $\mathrm{BER_H} = 10^{-3}$ (i.e., -30dB) are used in simulations. Moreover, the step scale between any two adjacent pilot spacings is set to 3. Note that a dense pilot pattern $L = 6$ is employed at an initial mode in simulations. Subsequently, the evaluated BER is fed back to the transmitter in order to make an appropriate decision on the number of pilots (i.e., the value of $L(l)$ in (6)), which are used to insert into the next OFDM block. In what follows, $\lambda = 0$ in (3) is used unless mentioned in advanced and the legends “linear” and “second-order” in figures denote, respectively, the adopted piecewise-linear and the second-order polynomial interpolation schemes of the comb-type channel estimation at the pilot subcarriers.

Experimental results in Figs. 1 and 2 show that the proposed adaptive pilot approach possesses superior BW efficiency and produces comparable BER performance while compared with conventional fixed-pilot channel estimation schemes employing dense pilot tones ($L = 6$). In particular, it should be noticed from both Figures that interpolation schemes with the use of $\lambda = 0.3$ enhance significantly the BW efficiency and the BER performance simultaneously, especially when the SNR is lower than 10dB. This fact implies that the use of the estimated channel from past OFDM blocks assists the receiver to improve system performance at low SNR condition and thus makes BW utilization more efficient. Additionally, results in Fig. 2 demonstrate that the interpolation-based estimation with the use of an adaptive pilot mode does not perform as well as the conventional fixed pilot scheme with $L = 6$ in BER performance but does provide substantial benefits in BW efficiency. Moreover, it is observed from Figs. 1 and 2 that the fixed sparse pilot scheme (i.e., $L = 30$) degrades the BER performance severely and thus results in a poor BW efficiency.

V. CONCLUSIONS

In this paper, a novel dynamic pilot-symbol assignment technique is proposed to enhance BW efficiency and to improve system performance in a pilot-assisted OFDM communication system. It makes the usage of the very limited BW more efficient. It is also verified from computer simulations that this adjustable pilot-symbol assignment scheme is feasible in real world and its BW efficiency is satisfactory.

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TABLE I

OFDM SYSTEM PARAMETERS

FFT Size	2048
Modulation	QPSK
Guard Band	247
Modulation Subcarriers	1801
Guard Interval	50
Sampling Period (μs)	0.1
Pilot Number (N_P)	301,201,151,…,61
Pilot Spacing (L)	6,9,12,…,30

TABLE II

CHANNEL PARAMETERS – 802.16a SUI-4 [8]

	Tap 1	Tap 2	Tap 3
Delay (μs)	0	1.5	4
Power (dB)	0	-4	-8
Doppler (Hz)	0.4	0.4	0.4

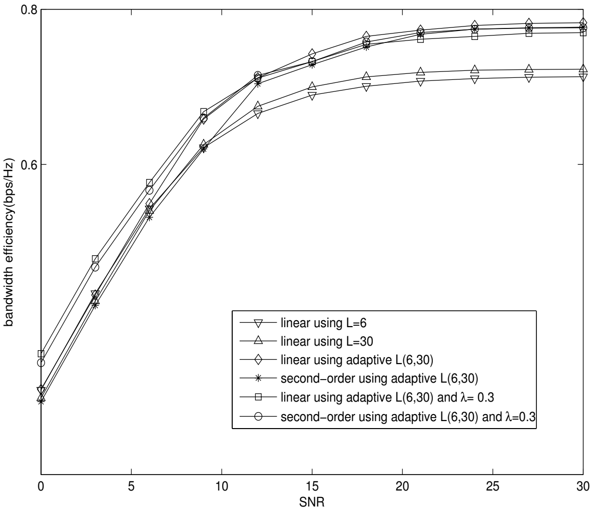

Fig. 1. BW efficiency of an adaptive pilot-assisted OFDM compared with the fixed pilot OFDM.

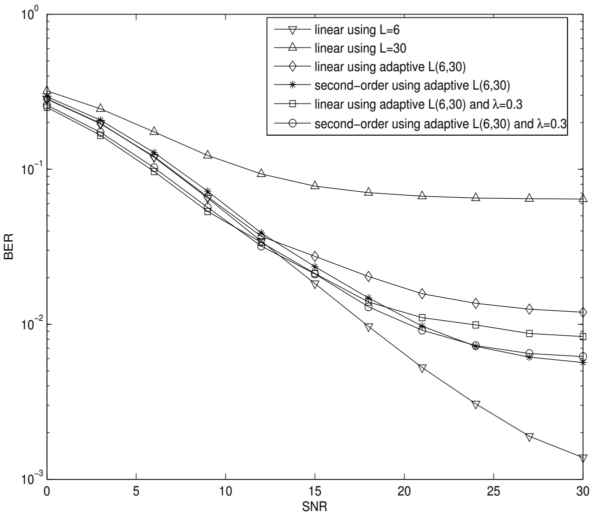

Fig. 2. BER performance of an adaptive pilot-assisted OFDM compared with the fixed pilot OFDM.