Short OFDM Preamble for Channel Estimation in Real-Time Wireless Control Systems

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1 Introduction

Wireless control systems are expected to overcome the disadvantages of wired control systems such as wiring cost and machine deployment constraints. High-speed control systems, which are currently operated via a field bus, require real-time capability and also scalability [1]. To realize real-time communication such that the periodic information exchange between a controller and all terminal devices finishes within 1 ms [1], the communication overhead such as preamble transmission has to be shortened. However, the performance of channel estimation degrades due to shorter preambles and it results in higher transmission error [2].

In this paper, we propose subcarrier-selected short preambles for channel estimation. A preamble is shortened by deliberately selecting a subset of subcarriers in an OFDM system. A channel estimation utilizes a previous channel estimate to exploit the periodic transmission of short preambles in which their subcarriers are shifted linearly between communication cycles. The simulation shows the performance comparison between full-length preambles and subcarrier-selected short preambles in terms of mean-square error (MSE) of channel estimation.

2 Preamble Shortening

Let us consider an OFDM system with preamble-aided channel estimation. The allocation of preamble and data subcarriers on the time-frequency grids is shown in Fig. 1, where the shaded grids represent preamble subcarriers, and the patterned grids show the data. Traditionally, the preamble transmission occupies all OFDM subcarriers as shown in Fig. 1a to allow individual channel estimation of each subcarrier. In addition, channel estimation among communication cycles are performed independently. However, due to the overhead of the full-length preamble compared to small data payloads, subcarrier-selected short preamble is considered for fast-cycle communication in wireless control systems.

Without loss of generality, we consider a short preamble with a shortening ratio \( C = 2 \) as an example. As demonstrated in Fig. 1b, the short preamble with half length is achieved by assigning training signals to half of selected subcarriers, whereas another half of the subcarriers are intentionally nulled out and marked as zeros. To guarantee the repeating property in time domain where the magnitude of time-domain preamble is repeated, due to properties of Fourier transform, we deliberately select subcarriers with either even or odd index numbers for a preamble symbol. Particularly, while the even-indexed subcarriers are being selected, the time-domain preamble is consisted of two identical copies repeating in series; if the odd-indexed subcarriers are being selected, the second half of the time-domain preamble is a phase-rotated version of the first half. By utilizing the repeating property, preamble can be shortened down by sending only one copy of the signal.

To apply our proposal in practical systems, the subcarrier-selected preamble is transformed by IFFT, the resulted signals are appended by a proper cyclic prefix (CP), and the repeated part are removed to form the short preamble. In the receivers, the CP is firstly removed, and the full preamble is then recovered by appending the phase-shifted copies to the received short preamble. Finally, the channel is estimated by the recovered full preamble.

3 Channel Estimation for Short Preambles

While the channel estimate of the selected subcarriers can be calculated by a normal channel estimation algorithm, the channel estimation on the nulled subcarriers cannot be performed directly. Frequency-domain interpolation could be applied to recover the complete channel estimate. In this work, in order to exploit the fast-cycle periodic communication of wireless control systems, we adopt the transmission of even-index-selected and odd-index-selected short preamble in a round-robin manner to allow cross-cycle time-domain interpolation to increase the channel estimation accuracy. For the channel estimation of nulled subcarriers, a simple cross-cycle time-domain zero-order-hold interpolation is adopted. That is, the channel estimates for nulled subcarriers are inherited from the last previous cycle.

4 Simulation

We evaluate the subcarrier-selected short preambles by comparing the MSE of channel estimation with that of full-length preambles. We consider an 802.11a-like OFDM system with the MMSE channel estimation [2]. Only one OFDM symbol of preamble is transmitted at the beginning of each cycle for channel estimation. A fixed-length CP of 1.6 ms is prepended to preamble to alleviate the ISI. The MSE is simulated under a frequency-selective fading channel of HIPERLAN/2 model C with different maximum Doppler frequencies and CNR, and the results are shown in Fig. 2.

Fig. 2 shows that the subcarrier-selected short preambles can provide comparable performance of channel estimation in relatively slow fading channel, or specifically, when the product of maximum Doppler shift and cycle time is less than 10 Hz ms.

References
