Adaptive Pilot Distribution for OFDM Systems in Time-Variant Channels

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Introduction

Due to its ability to resist multipath fading channels and its spectrum efficiency, Orthogonal Frequency Division Multiplexing (OFDM) has been chosen as a modulation scheme for high speed access systems, and became a promising candidate for 4G mobile communication systems. In OFDM the total bandwidth is divided into N mathematically orthogonal sub-carriers transmitted simultaneously utilizing Fast Fourier Transform (FFT) which allows the carriers to overlap each other making OFDM an efficient technique in terms of bandwidth. On the other hand, OFDM is sensitive to frequency offsets and phase noise. Doppler effect induces Inter-Carrier Interference (ICI) in time-variant channels, as it destroys the orthogonality of OFDM system and degrades its performance. Combating this problem requires continuous and complete channel matrix estimation. In order to estimate the channel, training symbols (pilots) are inserted among the transmitted data. The receiver compares between the transmitted and the received pilots to retrieve CSI. The pilot spacing in time and frequency must be designed according to the coherence time and coherence bandwidth of the channel, respectively. In recent years, many works have been introduced on designing the optimal training sequence for channel estimation. In [1], a design that minimizes the channel Mean Square Error (MSE) has been considered. An optimal design that minimizes the Cramer-Rao Bound (CRB) was investigated in [2]. In [3], a design of the optimal (least) number of pilots needed at a required BER and a given SNR was proposed. In time-variant wireless channels, the level of variation may change in time, where the conventional fixed-pattern of pilot distribution, that are usually designed for the worst-case condition, may cause unneeded loss of capacity, since the channel often behaves much better than the assumed worst-case. In this case an adaptive method for pilot distribution according to the variation level of the channel can be of interest. In OFDM system, the source bit stream is first coded and mapped using QAM or PSK, then some pilots for channel estimation are inserted before applying IFFT operation. In order to guarantee an ISI-free system, a guard interval with a length longer than the expected channel-impulse-response (CIR) is added to the OFDM symbol. The transmitted time domain signal is written as

$$x_n = \sum_{m=0}^{N-1} S_m e^{j\frac{2\pi nm}{N}} \qquad 0 \le n \le N-1 \ , \tag{1}$$

where S_m is the QAM/PSK symbol at the m^{th} sub-carrier. The transmitted signal is convolved with the L-path channel to produce the received signal as

$$y_n = \sum_{l=1}^{L} h_n^{(l)} x_{n-\tau_l} + v_n \ , \tag{2}$$

where $h_n^{(l)}$ and τ_l are the complex random variable and the corresponding tap delay, respectively that characterize the l^{th} path of the multipath channel , and v_n describes the

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additive white Gaussian noise at sample n. The k^{th} frequency domain carrier after FFT is written as

$$Y_k = S_k H_{k,k} + \underbrace{\sum_{\substack{m=0\\k\neq m}}^{N-1} S_m H_{m,k}}_{ICI} + V_k \ , \tag{3}$$

where $H_{k,m}$ is an element of the frequency domain channel matrix $\mathbf{H}$. In time-invariant channels, $\mathbf{H}$ has a diagonal structure, and loses its diagonality in time-variant channels, thus the sub-diagonals represent the ICI strength that reflects the variation level of the channel caused by Doppler effect. $H_{k,m}$ can be expressed as

$$H_{m,k} = \frac{1}{N}\sum_{n=0}^{N-1} U_m(n) e^{-j\frac{2\pi}{N}n(k-m)} \ , \tag{4}$$

where $U_m(n)$ is the two dimensional time varying channel weights for each sub-carrier m and time sample n.

Adaptive Pilot Distribution

The channel coefficients can be estimated at the positions of the transmitted pilots and then an interpolation method is applied over all the carriers. A low complexity technique the estimation of the channel matrix is done by estimating the main diagonal of the channel matrix using Wiener filtering as in [4], while other elements of $\mathbf{H}$ are estimated by approximating the time variation between three successive symbols [5]. Using (4), the main diagonal elements of $\mathbf{H}$ can be written as

$$H_{k,k} = \frac{1}{N}\sum_{n=0}^{N-1} U_k(n) = \overline{U}_k \ , \tag{5}$$

where $\overline{U}_k$ is a representation of $U_k(n)$ in the middle of the symbol. By making use of the first three terms of a Taylor expansion one can write

$$U_k(n) \approx \overline{U}_k + (n - \frac{N-1}{2})\overline{U}_k{}' + (n - \frac{N-1}{2})^2 \frac{\overline{U}_k{}''}{2} \ , \tag{6}$$

$\overline{U}_k{}'$ and $\overline{U}_k{}''$ are the derivatives of $\overline{U}_k$ calculated from the adjacent symbols of the symbol of interest. After approximating $U_k(n)$, $\mathbf{H}$ can be calculated relying on (4). Using the estimated channel matrix in (4), the ICI power for an arbitrary subcarrier is calculated [6] as

$$P_{ICI} = \sum_{k\neq m} E\left\{ \left| H_{k,m} \right|^2 \right\}. \tag{7}$$

Doppler spread can be roughly estimated from the ICI power using an approximation given in [7] as

$$f_d \approx \frac{\sqrt{3P_{ICI}}}{\pi T_s} \tag{8}$$

where T_s is the total symbol duration. Adaptive techniques are only suitable for (bidirectional) communications. In a WLAN system, the modulation level and coding rate are adapted according to the SNR of the received signal. According to the same concept, the distribution of pilots can also be adapted to the estimated Doppler spread. Pilots are inserted in blocks of three successive symbols as shown in Fig. 1, and the distance between these blocks changes with the estimated Doppler spread.

Simulation and Conclusion

An OFDM-based WLAN system in time-variant environment has been considered. 4-tap and 2-tap channels with a maximum delay spread of 550ns were used. Uncoded QPSK symbols were used and perfect synchronization was assumed. A more realistic assumption is to let the level of variation of the channel changes between fast and very slow. Six threshold levels of the Doppler spread have been chosen for the adaptive pilot arrangement. The simulation results in Fig. 2 show an increase in the bit rate when the channel is static or slowly varying. Whereas in the rapidly varying cases the bit rate falls down to the conventional one (24 Mbps). In Fig. 2 the bit rate has been averaged every 500 symbols. It was shown that the adaptive method increases the total capacity of the system. The gain in the throughput is noticeable for slow varying and static channels. We noticed that, by choosing proper threshold levels, the adaptive system is comparable in the BER performance with the conventional one as shown in Fig. 3.

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Figures

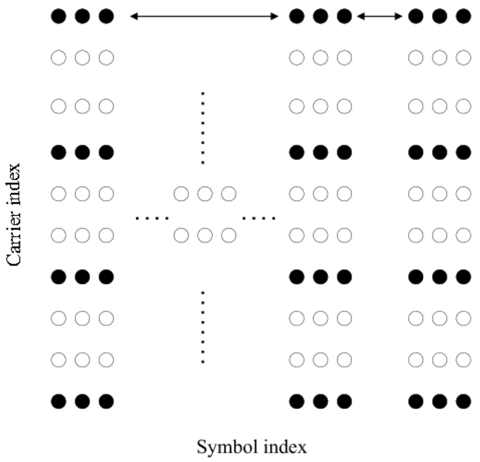

Fig. 1. Adapting the time-spacing between the pilots.

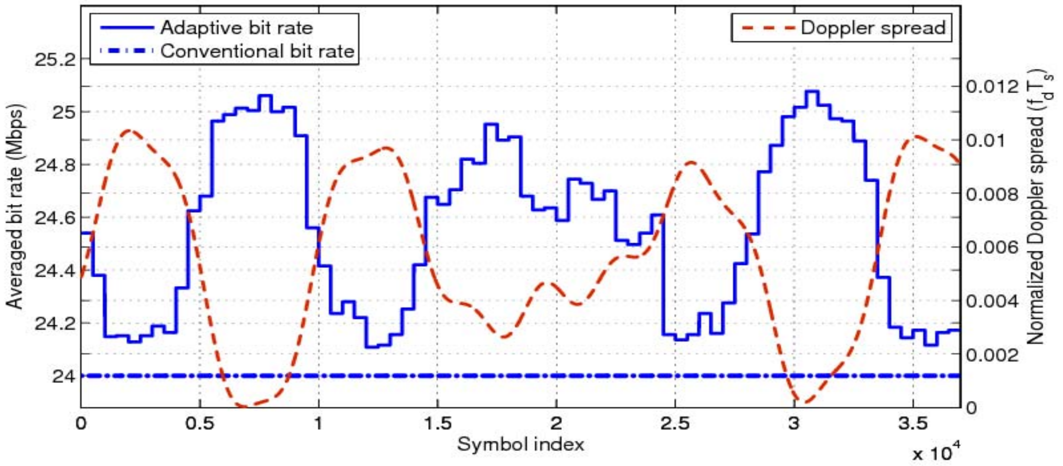

Fig. 2. Adaptive bit rate vs. Doppler spread

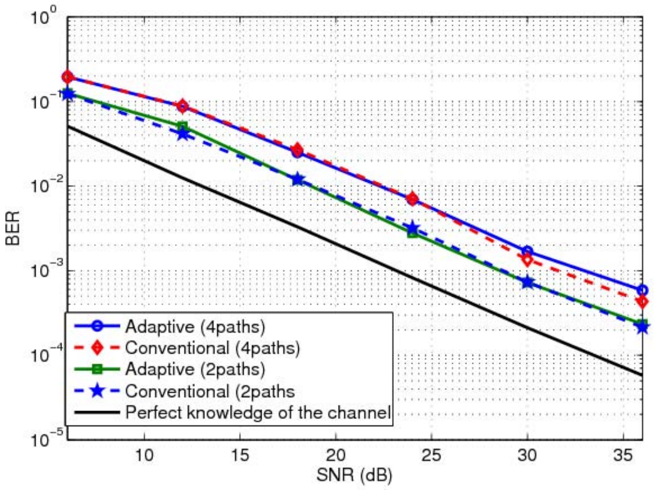

Fig. 3. System performance: BER vs. SNR.