Pilot signaling for multi-cell OFDMA uplink systems

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Abstract

OFDMA is considered as one of the major candidates for broadband wireless access. The OFDMA signal is usually coherently demodulated, requiring the channel estimation which can be estimated using a known pilot signal. In multi-cell environment, the performance of channel estimation is mainly limited by intercell interference. It is desirable to use a pilot signal that can estimate the channel information robust to the intercell interference in the OFDMA uplink system. In this paper, we consider two types of pilot signal applicable to multi-cell OFDMA uplink systems: One is time-multiplexed pilot signal and the other is code-multiplexed pilot signal. Simulation results show that the code-multiplexed pilot is suitable for low mobility environment and time-multiplexed pilot is suitable for high mobility environment.

1. Introduction

Orthogonal frequency division multiple access (OFDMA) is a multiple access scheme based on the OFDM technology, where each user uses different subcarriers [1]. The OFDMA consider the use of frequency hopping to exploit the frequency diversity of channel, mitigating the effect of fading [2, 3].

For coherent demodulation of OFDMA signal, the channel information can be estimated using a pilot signal [4-7]. In the downlink system, a common pilot signal is transmitted with high transmit power, enabling accurate estimate of the channel information. However, since each user experiences different channel condition in the uplink, it is required to transmit user dedicated pilot symbols. The transmit power of the dedicated pilot signal in the uplink is usually less than that of the common pilot signal in the downlink. As a result, it may not be easy to obtain the channel estimation performance in the uplink as good as in the downlink. In this paper, we consider the design of pilot signal in the uplink system, where the channel estimation is a more important issue.

In multi-cell environment with a high frequency reuse factor, the channel estimation performance is mainly limited by intercell interference whose power is varying in time and frequency. In this paper, we consider the use of two types of pilot signal in multi-cell OFDMA uplink systems: One is time-multiplexed pilot signal and the other is code-multiplexed pilot signal.

2. System model

Fig. 1 depicts the block diagram of an OFDMA uplink system with frequency hopping. The encoded data bits are interleaved and mapped into a quadrature amplitude modulation (QAM) type signal after being multiplexed with the pilot signal. Each user signal has an N-symbol time duration and is frequency hopped to obtain the frequency diversity as illustrated in Fig. 2.

The transmit signal $\mathbf{s}_j$ of the j-th subcarrier with some hopping unit can be defined as

$$\mathbf{s}_j = \left[s_{1,j} \; s_{2,j} \; \cdots \; s_{N,j} \right]^T \tag{1}$$

where $s_{i,j}$ is the i-th transmit symbol unit assigned to the j-th subcarrier. Then the frequency domain signal is transformed into a time domain signal by N_c-point inverse fast Fourier transform (IFFT) operation. Finally a cyclic prefix is added to mitigate the intersymbol and intercarrier interference.

The received signal is converted into a frequency domain signal using the FFT process after removing the cyclic prefix. Assuming perfect timing and frequency synchronization, the received signal $\mathbf{r}_j = \left[r_{1,j} \; r_{2,j} \; \cdots \; r_{N,j} \right]^T$ at the j-th subcarrier after the inverse hopping process can be expressed as

$$\mathbf{r}_j = \mathbf{H}_j \mathbf{s}_j + \mathbf{n}_j + \boldsymbol{\psi}_j \tag{2}$$

where $\mathbf{H}_j = diag(H_{1,j}\ H_{2,j}\ \cdots\ H_{N,j})$ is the channel gain at the j-th subcarrier, and $\mathbf{n}_j = \left[n_{1,j}\ n_{2,j}\ \cdots\ n_{N,j}\right]^T$ and $\boldsymbol{\psi}_j = \left[\psi_{1,j}\ \psi_{2,j}\ \cdots\ \psi_{N,j}\right]^T$ are additive white Gaussian noise (AWGN) and intercell interference at the j-th subcarrier, respectively. The channel impulse response (CIR) can be estimated using the pilot signal for coherent demodulation.

3. Design of pilot signal

We consider two types of pilot signal. One is time multiplexed pilot signal and the other is code multiplexed pilot signal.

When the user signal is time-multiplexed with the pilot signal, the transmit signal $\mathbf{s}_j^{(T)}$ can be expressed as

$$\begin{aligned}\mathbf{s}_j^{(T)} &= [s_{1,j}^{(T)}\ s_{2,j}^{(T)}\ \cdots\ s_{N,j}^{(T)}] \\ &= \left[d_{1,j}\ \cdots\ d_{i-1,j}\ p_j\ d_{i,j}\ \cdots\ d_{N-1,j}\right]^T\end{aligned} \tag{3}$$

where $d_{i,j}$ denotes the j-th data symbol at the i-th OFDM symbol time and p_j denotes the pilot symbol transmitted through the j-th subcarrier. From the received signal (2), the channel impulse response (CIR) can be estimated as

$$\hat{H}_j = r_{i,j} / p_j = H_{i,j} + (n_{i,j} + \psi_{i,j}) / p_j \tag{4}$$

where $H_{i,j}$ is the complex channel gain of the j-th subcarrier at the i-th symbol time and $(n_{i,j} + \psi_{i,j}) / p_j$ is the background noise and intercell interference term. The estimated channel information is used for coherent detection of (N-1) data symbols of the j-th subcarrier, i.e.,

$$\hat{\mathbf{H}}_j = [\ \hat{H}_j\ \ \hat{H}_j\ \ \cdots\ \hat{H}_j]^T. \tag{5}$$

In a code multiplexed pilot scheme, the pilot symbol is spread in the time domain to mitigate the intercell interference. When the data is code-multiplexed with the pilot symbol, the transmit signal $\mathbf{s}_j^{(C)}$ of the j-th subcarrier can be expressed as

$$\begin{aligned}\mathbf{s}_j^{(C)} &= [s_{1,j}^{(C)}\ s_{2,j}^{(C)}\ \cdots\ s_{N,j}^{(C)}] \\ &= \mathbf{c}_1 d_{1,j} + \cdots + \mathbf{c}_{N-1} d_{N-1,j} + \mathbf{c}_N p_j\end{aligned} \tag{6}$$

where $\mathbf{c}_m = \left[c_{m,1}\ c_{m,2}\ \cdots\ c_{m,N}\right]^T$ represents the m-th spreading code with unit power (i.e., $\mathbf{c}_m^T \mathbf{c}_m = 1$).

In the receiver, the CIR can be estimated by despreading the pilot symbol as

$$\begin{aligned}\hat{H}_j &= \frac{1}{p_j}\sum_{i=1}^{N}(H_{i,j}s_{i,j} + n_{i,j} + \psi_{i,j})c_{N,i} \\ &= \frac{1}{N}\sum_{i=1}^{N}H_{i,j} + \frac{1}{p_j}\sum_{i=1}^{N}(n_{i,j} + \psi_{i,j})c_{N,i} \\ &\quad + \frac{1}{p_j}\sum_{i=1}^{N}\sum_{m=1}^{N-1} d_{m,j}c_{m,i}c_{N,i}H_{i,j}\end{aligned} \tag{7}$$

where the first term is the channel gain, the second term is the background noise plus intercell interference averaged over N OFDM symbols, and the last term is the inter-code interference due to the time variation of the channel. Assuming a quasi stationary channel such that

$$H_j = H_{i,j},\ i = 1, 2, \cdots, N \tag{8}$$

(7) can be rewritten as

$$\hat{H}_j = H_j + \frac{1}{p_j}\sum_{i=1}^{N}(n_{i,j} + \psi_{i,j})c_{N,i}\ . \tag{9}$$

It can be seen that pilot spreading can reduce the variation of the interference power using the effect of averaging.

The difference of estimated channel gain between the time-multiplexed and code-multiplexed pilot scheme is in the statistics of intercell interference. When the time-varying characteristics of the intercell interference are not properly mitigated in the time-multiplexed pilot scheme, the channel estimation can very be sensitive to the power variation of intercell interference. On the other hand, the intercell interference is averaged over N OFDM symbols in the code-multiplexed pilot scheme, mitigating the time selective characteristics of intercell interference.

4. Performance evaluation

To evaluate the performance of the channel estimation, we consider the use of Walsh-Hadamard codes with spreading factor 4 for the code multiplexed pilot signal. For comparison, a single pilot symbol is time-multiplexed with data symbols in the second OFDM symbol. The total power of the pilot signal is 3dB lower than that of the data signal. We consider the use of zig-zag codes with code rate 1/2 and 5/6 as the channel coder [10]. For simulation, we assume Rayleigh fading channel having 18 independent path with path loss exponent 4 and Doppler frequency 30Hz, 300Hz and 600Hz, corresponding to 6km/h, 60km/h and 120km/h user mobility at carrier frequency 5.4GHz, respectively. We also assumed that every cell uses the same frequency band and that one half of total subcarriers are in active on the average. Since the system performance is mainly limited by the intercell interference in multicell environment, we only consider the intercell interference, i.e., we ignore the background noise.

Fig. 3 and 4 depict the average PER performance at Doppler frequency 30Hz and 300Hz, respectively. With the use of code rate 5/6, it can be seen that the PER performance can be improved by employing code multiplexed pilot signal. This is mainly due to that the power variation of intercell interference can be mitigated by the pilot signal spreading, while the channel coding cannot sufficiently mitigate the intercell interference. However, It can be seen that both pilot multiplexing schemes have similar performance with the use of code rate 1/2. This is mainly due to that the intercell interference is sufficiently averaged enough by the channel decoder. Since 16-QAM is more sensitive to the performance of the channel estimation, the effect of channel estimation error in the 16-QAM scheme is larger than that in the QPSK scheme.

Fig. 5 depicts the PER performance when the Doppler frequency is 600Hz. It can be seen that the PER performance deteriorates with the use of pilot signal spreading. This is mainly due to that the channel can be changed significantly over the hopping time NT_s. Since additional interference term is unavoidable due to the destruction of code orthogonality at high Doppler frequency, the performance degradation due to the intercode interference is larger than the performance improvement from the intercell interference averaging. It can be seen that the effect of intercode interference becomes larger when the modulation order increases and/or the code rate increases.

It can be inferred that the use of code-multiplexed pilot signal is more proper mitigating intercell interference in low mobility environment. On the other hand, the use of time-multiplexed pilot signal is applicable in high mobility environment. For adaptive pilot signaling, the Doppler frequency can be estimated with an affordable implementation complexity [11, 12].

5. Conclusions

We have considered two types of pilot signaling in multi-cell uplink OFDMA system. The use of the code-multiplexed pilot signal can mitigate intercell interference by introducing pilot signal spreading. However, code-multiplexed pilot signal introduces intercode interference in high mobility environment. The simulation results verify that the code-multiplexed pilot signal is appropriate in low mobility environment and the time-multiplexed pilot signal is appropriate in high mobility environment.

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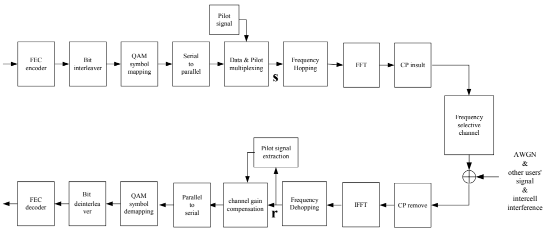


Fig. 1. Frequency hopping OFDMA uplink system

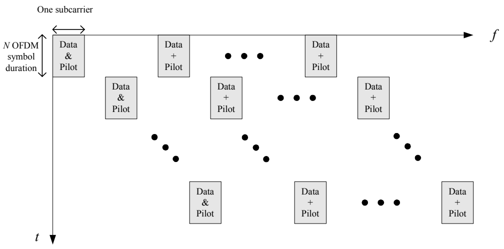
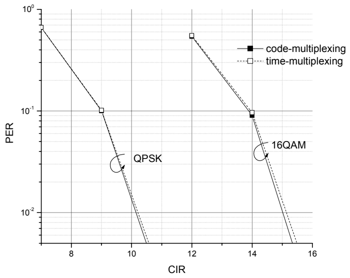
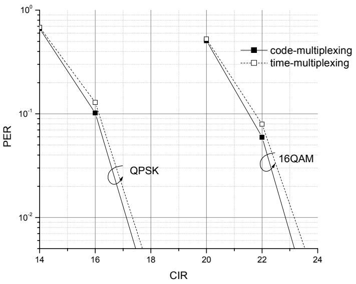


Fig. 2. Frequency hopping in the OFDMA uplink

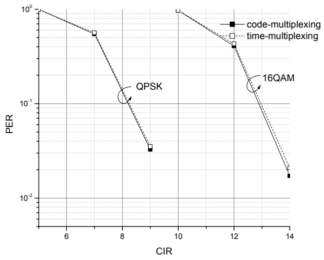


(a) Code rate =1/2

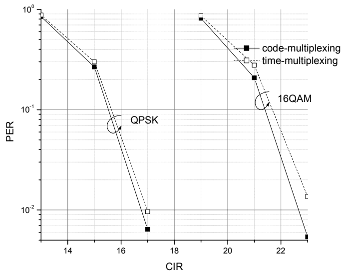


(b) Code rate = 5/6

Fig. 3. The PER performance at f_d =30Hz

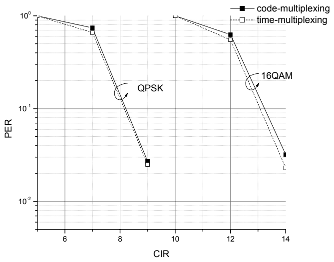


(a) Code rate =1/2

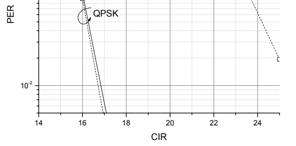


(b) Code rate = 5/6

Fig. 4. The PER performance at f_d =300Hz



(a) Code rate =1/2



(b) Code rate = 5/6

Fig. 5. The PER performance at f_d =600Hz