A SUPERIMPOSED PERIODIC PILOT SCHEME FOR SEMI-BLIND CHANNEL ESTIMATION OF OFDM SYSTEMS

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ABSTRACT

An attractive feature of the Orthogonal Frequency Division Multiplexing (OFDM) system is its simple one-tap equalizer for linear channel distortions. Nevertheless, one still has to address the channel estimation issue. In mobile environments, self-recovery methods that avoid any recurring training overhead are of interest. In this paper, we propose a superimposed pilot scheme employing only a first-order statistic to identify the channel for OFDM systems. It can be regarded as a semi-blind method and does not require dedicated slots for training. This scheme allows for simple channel estimation as well as equalization, with no loss of spectral efficiency.

1. INTRODUCTION

The Orthogonal Frequency Division Multiplexing (OFDM) system has attracted considerable interests for mitigating inter-symbol interference (ISI) in high speed data communications systems, such as mobile radio systems, digital audio/video broadcasting, and wireless LAN systems. OFDM is a block modulation scheme where data symbols are multiplexed onto a (large) number of orthogonal sub-carriers, and then transmitted in parallel [1]. In OFDM, the use of cyclic prefix (or suffix), or a guard interval (GI), converts linear convolution between the transmitted signal and the channel into circular convolution, and therefore frequency selectivity of the mobile fading channel appears to be flat on each sub-carrier.

Differential modulation/demodulation techniques, such as DPSK, can be combined with OFDM to offer the advantage of avoiding channel estimation at the expense of performance reduction. Coherent modulation, on the other hand, gives better performance, but one has to face the channel estimation issue. Our interest, therefore, will focus on coherent OFDM system with a low-complexity channel estimator.

Pilot-symbol assisted modulation (PSAM) is commonly used for channel identification in a flat fading environment. Training pilots are inserted into certain positions in the time and frequency grids of OFDM data blocks, and channel identification is performed by 2-D interpolation [2] [3]. However, these training symbols consume valuable bandwidth in a mobile environment. Therefore, self-recovery methods that avoid any recurring training overhead are of interest. More recently, C. K. Ho *et al.* [4] proposed an added pilot semi-blind scheme used for channel estimation of OFDM systems, which employs second-order statistics for channel estimation followed by a 2-D Wiener filter to remove the pilots. Data estimates are obtained from the channel estimates. Based on the estimated data, another iteration of channel-data estimation is performed to improve the accuracy.

In this paper, we propose a superimposed pilot scheme to identify the channel, which employs only a first-order statistic. It can be regarded as a semi-blind method and does not require dedicated slots for training. This scheme allows for simple channel estimation as well as equalization, with no loss of spectral efficiency. Under our framework, periodic pilots are added to each block of time-domain OFDM symbols before transmission, and the ith channel tap gain is identified at the receiver by averaging over every ith sample of each sub-block in the received OFDM symbol blocks. The demodulator removes the distorted pilots based on the channel estimates, and converts the blocks of OFDM symbols into the frequency-domain. Finally, the data estimates are obtained after a frequency-domain single-tap equalizer.

2. SYSTEM MODEL

The baseband system model is shown in Fig. 1. A block of N serial data symbols $X_i(n)$, which are often chosen from the QAM or PSK constellations in OFDM systems, is modulated onto N orthogonal subcarriers using N-point IFFT by the OFDM modulator to generate the ith block time-domain data symbols

$$x_i(k) = \frac{1}{N}\sum_{n=0}^{N-1} X_i(n)e^{j\frac{2\pi nk}{N}}, \qquad 0 \le k \le N-1. \quad (1)$$

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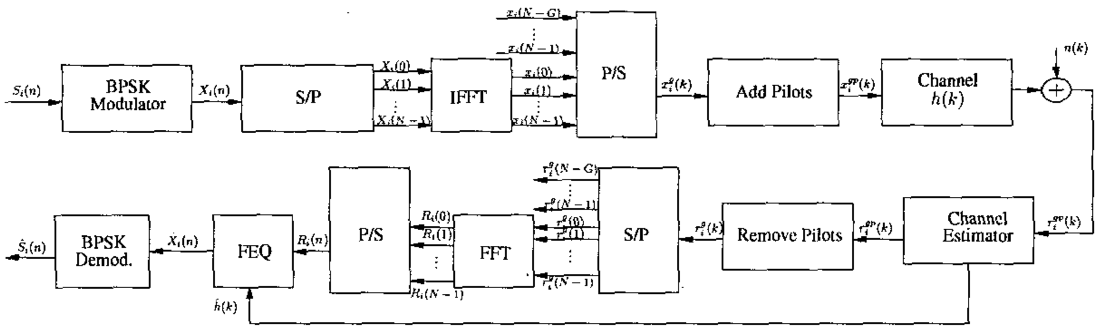


Fig. 1: OFDM system baseband model.

The guard interval, cyclic prefix in this model, is inserted into the ith block of IFFT coefficients [5]:

$$x^g(k) = x(k+N-G)_N, \qquad 0 \le k \le N+G-1, \quad (2)$$

where G is the length of the guard interval and $(k)_N$ is the residue of k modulo N. The index i will be dropped as in (2) for simplicity. The pilot sequence is then added to each block of data symbols to generate the baseband channel signal:

$$x^{gp}(k) = x^g(k) + p(k), \qquad 0 \le k \le N+G-1. \quad (3)$$

A simple and effective choice of $p(k)$ is

$$p(k) = \sum_{m=0}^{R-1} a\,\delta(k-mP), \qquad 0 \le k \le N+G-1, \quad (4)$$

where $\delta(\cdot)$ is the Kronecker delta function, P is the period, and $R = \lfloor (N+G)/P \rfloor$ is the number of periods.

The data sequence $x^{gp}(k)$ is transmitted through the ISI channel with additive noise, resulting in the received signal

$$r^{gp}(k) = x^{gp}(k) \star h(k) + n(k), 0 \le k \le N+G-1, \quad (5)$$

where $h(k)$ is the channel impulse response of length L, $\star$ denotes the linear convolution, and $n(k)$ is additive noise.

Define the mth length-P sub-block of $r^{gp}(k)$ as $r_m^{gp}(k) = r^{gp}(mP+k), 0 \le m \le R-1, 0 \le k \le P-1$. By assuming that both the source signal $X(n)$ and the noise $n(k)$ are zero mean, it follows easily that [6]

$$\hat{h}(k) = \frac{1}{aR}\sum_{m=0}^{R-1} r_m^{gp}(k), \;\; L \le P, \; 0 \le k \le P-1, \quad (6)$$

where $\hat{h}(k)$ is the linear channel estimator with $L \le P$.

Table 1: Nonzero taps of the channel ($h_n = 0$, elsewhere).

n	h_0	h_1	h_5	h_8	h_{25}	h_{33}
$h(n)$	0.405	0.541	0.383	0.307	0.430	0.342

The demodulator removes the guard interval and the pilot sequence, and then performs an N-pilot FFT on the resulting sequence. The demodulated sequence $R(n)$ is then equalized by a single-tap equalizer

$$\hat{X}(n) = \frac{1}{\hat{H}(n)} R(n), \qquad 0 \le n \le N-1, \qquad (7)$$

where $\hat{H}(n) = \sum_{k=0}^{P-1} \hat{h}(k) e^{-j\frac{2\pi kn}{N}}$. The symbol detector then make decisions on $\hat{X}(n)$ to extract the source data symbols $\hat{S}(n)$.

3. SIMULATIONS

In this section, we illustrate through computer simulations, the symbol error rate (SER) performance of the superimposed pilot scheme for OFDM systems. We first analyze the SER performance as a function of the pilot amplitude and block length. Next, the tradeoff between these two parameters and the peak-to-average power ratio (PAPR) is addressed. Finally, we compare the SER performance for different modulation formats with varying pilot amplitudes, which are carefully chosen to provide the best compromise for the SER/PAPR tradeoff which will be addressed in Section 3.2.

In our simulations, the static ISI channel is taken from [1] which has length $L = 34$. Most tap gains are zero and the six nonzero tap gains are listed in Table 1. This channel has several deep subchannel nulls, and the smallest subchannel power is -23.3dB below the average subchannel power. It is a challenging case for the conventional PSAM scheme.

3.1. Pilot Amplitude and Block Length

The superimposed pilot sequence is known *a priori* by the transmitter and receiver and the pilot amplitude; i.e., a in

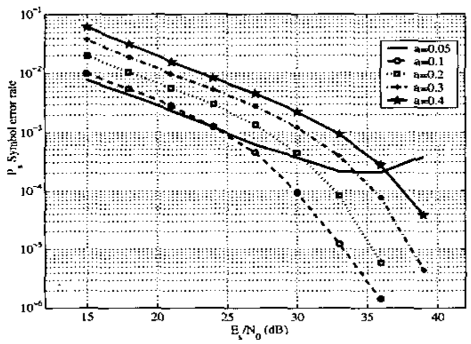


Fig. 2: SER versus E_s/N_0 for varying pilot amplitudes for BPSK symbols.

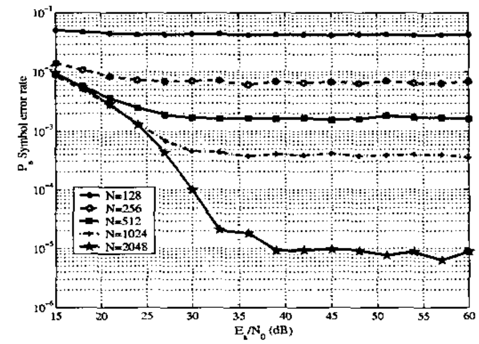


Fig. 3: SER versus E_s/N_0 for varying block lengths for BPSK symbols.

(4), is chosen to be real-valued for simplicity. Fig. 2 shows the SER performance for different values of the pilot amplitude for BPSK modulated symbols.

Note from (3) that instead of inserting the pilots into the OFDM symbols, they are superimposed onto $x^g(k)$ once every P symbols. Therefore, the unknown data symbols $x^g(k)$ have the effect of lowering channel estimation accuracy. For a fixed data symbol power level, the larger the pilot amplitude, the better accuracy of the channel estimation. In our simulations, the symbol energy to noise power spectral density (PSD) ratio (E_s/N_0) in Fig. 2 is defined as the channel symbol (the sum of data and pilots) power to additive noise power ratio. Therefore, a stronger pilot increases the transmitted power and introduces more distortion in the pilot removal stage, although it achieves better estimation of the channel. That is why the optimal SER performance is achieved with $a = 0.1$ in stead of higher values.

Block length is the number of sub-carriers for the OFDM system. Fig. 3 shows the SER performance for varying block lengths for BPSK symbols with a fixed pilot amplitude $a = 0.1$. We can see that the longer the block, the lower the SER. This is because the variance of the sample average in (6) is inversely proportional to the amount of available data samples. On the other hand, we know that inter-channel interference (ICI) in OFDM systems increases as the number of subcarriers increases and the maximum possible PAPR is N. Therefore the block length N has beneficial as well as detrimental effects.

3.2. Peak-to-Average Power Ratio

It is well known that a major impairment of an OFDM system is its high peak-to-average power ratio. Unfortunately, the superimposed pilots may add to the problem. We therefore need to be very careful in selecting the pilots and deciding on the block length. Fig. 4 shows the PAPR increment (dB) versus varying amplitudes of pilot for BPSK, QPSK, 16QAM, and 64QAM symbols with different block lengths. It is seen that PAPR for smaller constellations (e.g., BPSK) is more sensitive to increase in pilot strength.

As shown in Fig. 3, limiting the length of each block means insufficient data symbols for channel estimation, thereby increasing the SER. On the other hand, increasing the block length will increase PAPR of the modulated signal, and consequently the transmitted signal may suffer from spectra regrowth and in-band distortion when passing through a nonlinear power amplifier. Note from Figs. 2, 3, 4, that SER is more sensitive to the block length N rather than the pilot amplitude a, while PAPR is more sensitive to a rather than N. Thus, we first select a reasonably large N to satisfy the SER requirement, and then decrease the pilot amplitude to reduce the PAPR increment. The parameters listed in Table 2 provide the best compromise for this SER/PAPR tradeoff for the example presented here.

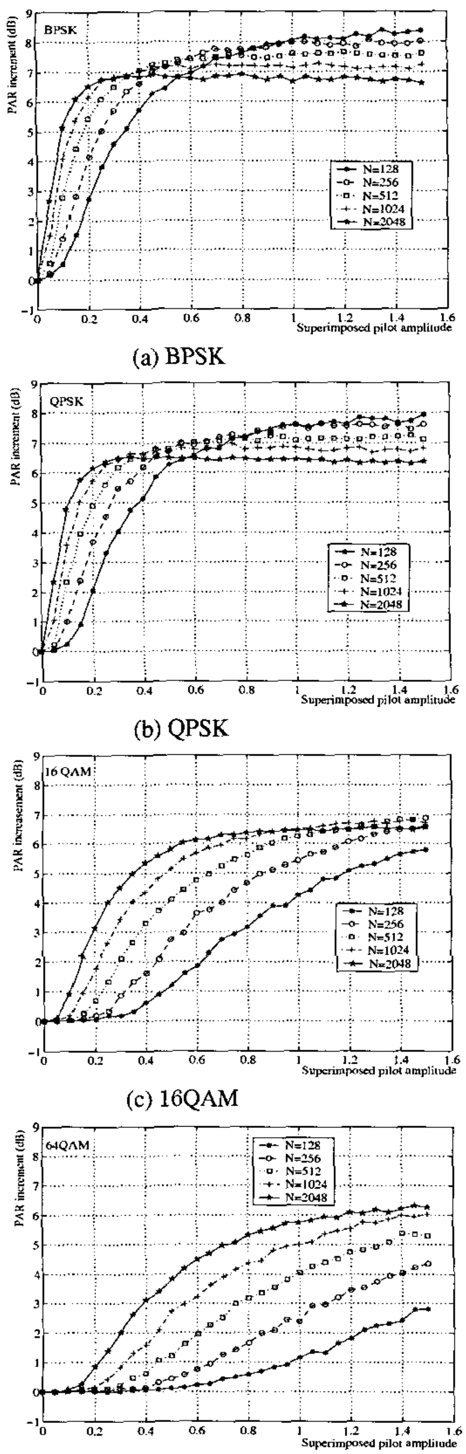
3.3. Comparison among Modulation Techniques

Fig. 5 shows SER versus E_s/N_0 for various coherent modulation techniques: BPSK, QPSK, 16QAM, and 64QAM. It can be seen that the superimposed pilot scheme performs better for smaller signal constellations, such as BPSK.

We also note from Fig. 5 that all these SER curves suffer from the error floor problem when E_s/N_0 is high; e.g., 40dB in our simulation. This is thought to be due to the signal playing a "noise" role in the channel estimation stage.

4. CONCLUSION

In this paper, we proposed a superimposed periodic pilot scheme for OFDM channel identification which employs only a first order statistic. The key features of this approach are simplicity and spectral efficiency. Performance of the proposed algorithm is demonstrated by numerical simulations. The future tasks will be the performance comparison with other transmitter introduced cyclostationarity or training methods, as well as the design of the pilot sequence for joint optimization of channel identification, symbol recovery and PAPR reduction.



(a) BPSK

(b) QPSK

(c) 16QAM

(d) 64QAM

Fig. 4: PAPR increment versus amplitude of pilot for different modulation techniques.

Table 2: Simulation parameters.

Length of source signal	2048 × 500
Block length (N)	2048
Channel length(L)	34
Guard internal (G)	128
Pilot period (P)	34
Pilot amplitude (a)	BPSK: 0.1 QPSK: 0.1 16QAM: 0.5 64QAM: 1.5

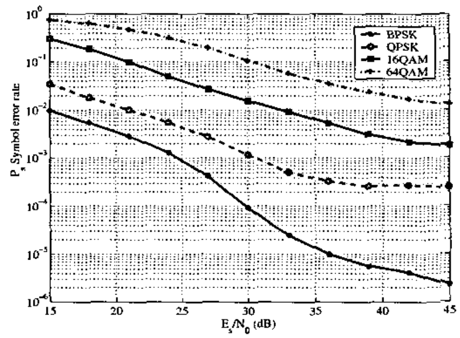


Fig. 5: Better SER performance is obtained with smaller signal constellations.

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