Preamble-aided time delay estimation in frequency selective channels for wireless OFDM systems

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Abstract: In this Letter, an improved method for estimating the time delay in preamble-aided orthogonal frequency division multiplexing systems is presented. It uses a conventional preamble structure and combines cross-correlation techniques to achieve estimations of time delay and the number of multipaths without any additional overhead. Computer simulations results show that the proposed method is of near-ideal property in frequency-selected channels.

1 Introduction

Coherent detection is utilised in wireless orthogonal frequency division multiplexing (OFDM) systems to achieve high data rate and good performance [1]. Channel estimation is essential to the coherent detection. In the pilot symbol assisted OFDM (PAS-OFDM) systems, the performance of channel estimation especially depends on the utilised pilot symbol patterns, which include the pilot allocation and number of pilots. In the frequency selective channels, the number of pilots in frequency domain are connected closely with the maximal time delay. Consequently, many methods involved with time delay estimation have been proposed.

Hui-liang *et al.* [2] estimated the channel parameters by transmitting the extra single component linear frequency modulation signal. It did not reduce the system's overhead. Athaudage and Jayalath [3] estimated the delay-spread by making use of auto-correlation between cyclic prefix and OFDM symbol trailer information. Suo-ping *et al.* [4] estimated the root-mean-square time delay and the value of maximal time delay threshold by using frequency domain correlation of pilots. They used the auto-correlation technique. Yang *et al.* [5] proposed a parametric channel estimation scheme using the eigenvalue decomposition method and rotational invariance technique (estimation of signal parameters by rotational invariance techniques (ESPRIT)). Subsequently, Raghavendra *et al.* [6] also used the two techniques to estimate the channel parameters, but the computational complexity of these two methods is high.

In this Letter, we will show an improved way to estimate time delay in frequency selective channel based on cross-correlation of preamble. The scheme not only has no additional system overhead, but also has lower complexity.

2 OFDM signal description

The equivalent baseband signal samples at the OFDM transmitter after inverse fast Fourier transform (IFFT) are given by

$$s(k) = \frac{1}{\sqrt{N}} \sum_{n=0}^{N_{\text{use}}-1} S(n) e^{j2\pi kn/N}; \quad n = 0, 1, \ldots, N-1 \qquad (1)$$

where N is the total number of subcarriers, with N_{use} being used. $S(n)$ represents the data modulated on the nth subcarrier, whereas $s(k)$ represents the symbols samples after IFFT processing. Each transmitted OFDM symbol is usually proceeded by a guard interval and cyclic prefix to resist the inter-symbol interference (ISI) arising from the multipath channel time delay.

At the receiver, the kth subcarrier in the nth OFDM symbol can be expressed as

$$r_k(n) = h(n) \otimes s_k(n) + w(n) \qquad (2)$$

where $s(n)$ is the transmitted symbol and $w(n)$ represents the zero-mean complex additive white Gaussian noise with variance δ^2, $\otimes$ is the convolution operation and $h(n)$ is the channel impulse response.

3 Proposed method

The proposed method is multi-stage, wherein the traditional preamble structure and cross-correlation technique are utilised to estimate the time delay and the location of multipath.

For packet-based communication, training symbols (preambles) are used for synchronisation and equalisation purposes in many literatures. Now preambles are utilised to estimate time delay without additional system overhead.

A preamble with two identical parts in time-domain is chosen as follows

$$S_{\text{sch}} = \left[A_{N/2} A_{N/2}\right] \qquad (3)$$

where $A_{N/2}$ is a random sequence of length $N/2$, generated as specified in [7].

Owing to most of the cross-correlation function energy focusing on the location of multipath, the cross-correlation function will yield a set of very sharp peaks (impulses) which indicate all the paths from the channel [8]. Assuming the channel has perfect synchronisation and there is no interference from the ISI, it means that the location of peak is the location of multipath.

The multipath estimation is derived as follows

$$P_x = \sum_{k=0}^{N-1} r(i+k) p^*(k) \qquad (4)$$

where $r(k)$ is presented as the received preamble symbols, $p(k)$ is the local preamble symbols, i represents the timing index and P_x is the cross-correlation function, and it is normalised to sequence $v_N(i)$, then the total energy is computed as

$$E_{\text{total}} = \sum_{i=0}^{L-1} |v_{\text{N}}(i)|^2, \quad i = 0, 1, 2, \ldots, L-1 \tag{5}$$

where $L = N/2$.

Then sort the sequence $v_{\text{N}}(i)$ to another sequence $v_{\text{N,sort}}(i)$ in descending order, and record the position corresponding to that of original sequence

$$i' = \text{location}\{v_{\text{N, sort}}(i)\}, \quad i' = 0, 1, 2, \ldots, L-1 \tag{6}$$

Accumulate the energy of sequence $v_{\text{N,sort}}(i)$ one by one, a new sequence of cumulative energy can be expressed as

$$E_N(i) = \sum_{j=0}^{i} |v_{\text{N, sort}}(j)|^2, \quad i = 0, 1, 2, \ldots, L-1 \tag{7}$$

Distinguish the location of $K(i)$ satisfying the following condition

$$i_0 = \arg\min_i \{K(i) \geq K\} \tag{8}$$

wherein energy ratio $K(i) = (E_{\text{N}}(i)/E_{\text{total}})$, $i = 0, 1, 2, \ldots, L-1$ and K is the threshold, obtained from the statistical calculations through the simulation, here $K \simeq 83\%$.

Extract the sequence $v_{\text{N,sort}}(i)$ from the range of $i = 0 \sim i_0$, and restore to the original location of the sequence

$$i_{\text{identify}} = \text{location}\{v_{\text{N, sort}}(i)\}, \quad i = 0, 1, 2, \ldots, i_0 \tag{9}$$

Then i_{identify} is the location of paths. From the results, the maximal time delay can be acquired.

4 Computer simulations

Numerous computer simulations have been carried out to verify the proposed method. The simulation parameters are summarised in Table 1. The length of cyclic prefix is 1/4 of 254, and the number of OFDM symbols in one frame is 62.

The Stanford University Interim (SUI) channel model is considered in our simulations and the uncorrelated multipath with a modified Jakes Doppler power spectrum is simulated. For simplicity, the channel coding is not considered.

Since the channels have certain randomness, in order to obtain the relatively stable information we will receive several frames to obtain the average information. Fig. 1 shows the veracity of estimating multipath time delay under different number of frames in signal-to-noise ratio (SNR) = 25 dB. From Fig. 1, when the number of frames are >50, the accuracy will reach 95–100%. As the duration of each frame is 5 ms, then the total time span of 50 frames is $T_{50\text{frame}} = 50 \times 5 = 250$ ms. According to the worldwide interoperability for microwave access standard, the highest mobile speed is 120 km/h so the mobile distance is about 8.3 m. Within such a distance, the channel does not have a large mutation. Therefore, the number of frames are 50 during the simulation.

Without loss of generality, in order to avoid the impact of fractional sampling delay, assume that the sample frequency is $F_s = 10$ MHz.

Fig. 2 (top) shows the normalised cross-correlation energy for different time delays and Fig. 2 (bottom) shows the identification of the number of multipaths for different time delays to the SUI-3 channel. It demonstrates that the energy of cross-correlation function always concentrates in the location of paths. Therefore, we can judge the number of paths from it. Based on the number of paths, the time delay and the maximal time delay can be computed. In Fig. 2, the simulation result is approximately equal as the SUI-3

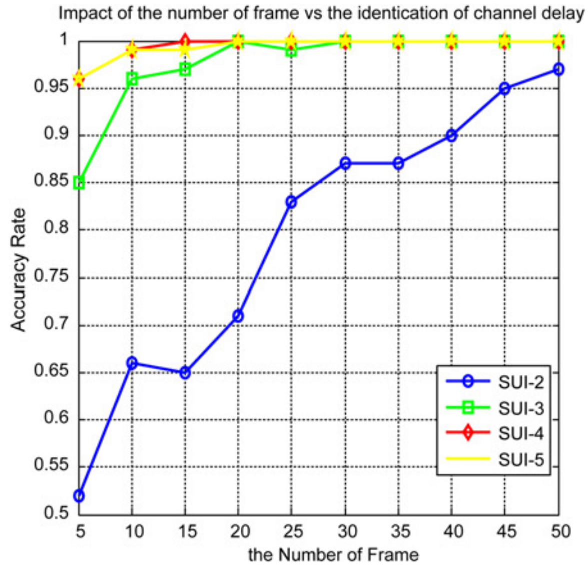

Fig. 1 *Veracity of estimating multipath time delay for various number of frames at SNR = 25 dB*

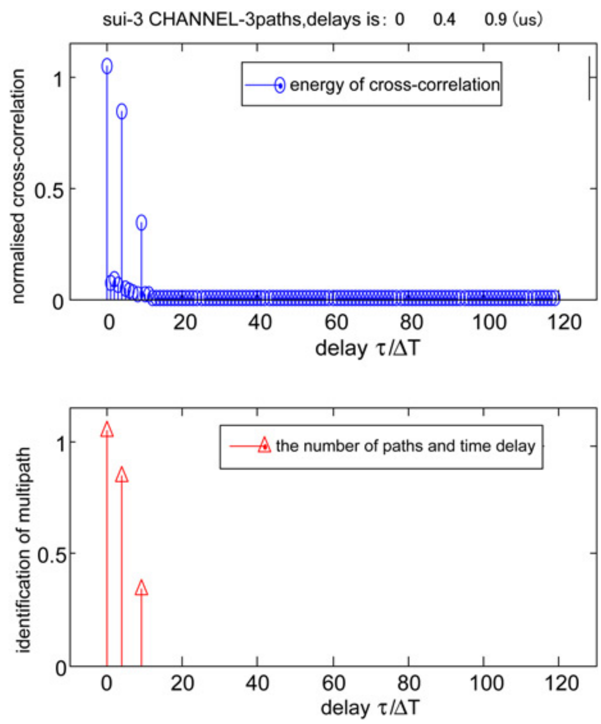

Fig. 2 *Normalised cross-correlation energy and multipath number of SUI_3 channels*

Table 1 Specifications

Parameters	Values
frequency range, GHz	2.4
modulation	16 quadrature amplitude modulation
FFT size	256
number of subcarriers	256
subcarrier spacing (Δf_c), kHz	150
channel model	SUI

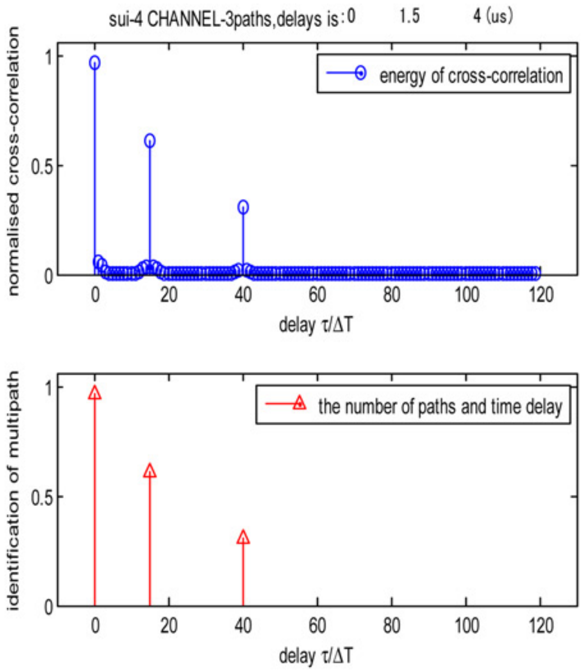

Fig. 3 *Normalised cross-correlation energy and multipath number of SUI_4 channels*

channel standard, namely, the number of paths is three and the time delay is 0, 0.4 and 0.9 µs.

To further verify the proposed method, the same simulation is also used in the SUI_4 channel. Fig. 3 verifies the validity of the proposed method in the SUI_4 channel. In Fig. 3, the time delay and the number of multipaths are nearly the same as the parameter of SUI_4 channel standard, that is, the number of paths is three and the time delay is 0, 1.5 and 4 µs.

5 Conclusion

In this Letter, an improved method for time delay in OFDM systems based on preamble cross-correlation is proposed. The number of frames for the simulation is also presented. Simulation results show that the method performs very well in frequency-selected channel. Furthermore, the algorithm does not consume additional system overhead.

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7 References

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