IMPROVED CHANNEL ESTIMATION FOR OFDM SYSTEMS IN QUASI-STATIC CHANNELS

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A low-complexity time-domain channel estimation technique for OFDM systems is proposed. It uses a training symbol (preamble) to estimate the channel impulse response (CIR) via circular cross-correlation. An efficient CIR search window technique is also proposed to optimise the accuracy of synchronisation and channel estimation. Simulation results in quasi-static channels show that the proposed method achieves near-ideal accuracy with a complexity which is much lower than that of the MMSE technique.

Introduction: Orthogonal Frequency Division Multiplexing (OFDM) is a popular technique in modern communications due to its spectral efficiency and robustness in the wideband channel [1]. OFDM has been implemented in many wireless systems such as DVB-T, DVB-H, DVB-SH, Wi-Fi and WiMAX. OFDM usually incorporates pilot tones and/or training symbols (preamble) to facilitate receiver estimation algorithms. Methods for OFDM channel estimation in the frequency domain (FD) have been studied extensively [1-3] resulting in a number of established approaches such as Least Squares (LS), Minimum Mean Square Error (MMSE) and Maximum Likelihood (ML). LS is computationally efficient but its accuracy is much lower than MMSE and ML which provide better performance at the cost of higher complexity. Time-domain (TD) channel estimation techniques are not as popular due to the negative impacts of imperfect synchronisation. However, it has been shown in [4] that near-ideal synchronisation can be achieved for OFDM systems in TD using one training symbol [4]. In systems where training symbols (preambles) are already used for other estimation purposes such as synchronisation, TD channel estimation becomes attractive in order to optimise the overall spectral efficiency. The TD approaches of [5] and [6] show good accuracy but suffer from significant processing delay and computational complexity. In this letter, we propose a TD technique which uses a preamble to achieve near-ideal channel estimation accuracy in quasi-static channel conditions, such as applies to WiFi and Fixed WiMAX systems. Apart from re-using the existing preamble, the method also has a significantly lower complexity than techniques such as MMSE. The proposed method combines synchronisation and channel estimation and it incorporates an efficient search window to achieve near-ideal accuracy even when the timing synchronisation of [4] is not ideal.

System model: The samples of an OFDM symbol at the output of the IFFT in the transmitter are given by:

$$x(k) = \frac{1}{\sqrt{N}} \sum_{n=0}^{N_{used}-1} X(n) e^{j2\pi k n/N}, \qquad 0 \le k \le N-1 \tag{1}$$

where N is the FFT size and N_{used} is the number of used subcarriers. $X(n)$ represents the data modulated on the n^{th} subcarrier while $x(k)$ represents the symbol samples after IFFT processing. Each transmitted OFDM symbol is usually preceded by a guard interval or cyclic prefix (CP) of length *G* in order to eliminate intersymbol interference (ISI) arising from the wideband channel.

Assuming sampling precision and perfect synchronisation, the complex-valued samples of the received signal can be represented as:

$$r(k) = \sum_{l=0}^{L-1} h(l)\, x(k-l) + w(k), \qquad 0 \le l \le G-1 \tag{2}$$

where $w(k)$ represents the zero-mean complex additive white Gaussian noise (AWGN) and $h(l)$ is the impulse response of the frequency-selective (ISI) channel whose memory order is *L*-1.

Proposed Method: The cross-correlation of the received signal and the transmitted preamble with m samples delay can be written as:

$$\gamma_m = \sum_{k=0}^{N-1} r(k) \cdot x^*(k-m), \qquad 0 \le m \le G-1 \tag{3}$$

where x^* is the complex conjugate of x. Combining (2) and (3), we have:

$$\gamma_m = \sum_{l=0}^{L-1} h_l \cdot \alpha_{m-l} + \beta(w), \tag{4}$$

$$\alpha_{m-l} = \sum_{k=0}^{N-1} x(k-l) \cdot x^*(k-m) \tag{5}$$

where α_{m-l} is the cross-correlation of the transmitted signal and its circular shift of $m-l$ samples in a CP-based OFDM system. $\beta(w)$ is the cross-correlation between transmitted signal and noise terms and will be neglected in the following paragraphs.

The concepts in (4) and (5) can also be represented in matrix and vector formats as:

$$\Gamma = \mathrm{A} \cdot \mathrm{H} \tag{5}$$

$$\Gamma = [\gamma_0 \, \gamma_1 \ldots \gamma_{G-1}]^T \tag{6}$$

$$\mathrm{H} = [h_0 \, h_1 \ldots h_{G-1}]^T \tag{7}$$

$$\mathrm{A} = \begin{bmatrix} \alpha_0 & \alpha_1 & \cdots & \alpha_{G-2} & \alpha_{G-1} \\ \alpha_{-1} & \alpha_0 & \cdots & \alpha_{G-1} & \alpha_{G-2} \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ \alpha_{2-G} & \alpha_{3-G} & \cdots & \alpha_0 & \alpha_1 \\ \alpha_{1-G} & \alpha_{2-G} & \cdots & \alpha_{-1} & \alpha_0 \end{bmatrix} \tag{8}$$

Since the values of the cross-correlation vector Γ can be obtained using (3) and the values of A are prior knowledge, the channel impulse response (CIR) vector H can be obtained by a $G \times G$ matrix inversion, given as:

$$\mathrm{H} = \mathrm{A}^{-1} \cdot \Gamma \tag{9}$$

The CIR can then be transformed to the channel frequency response (CFR) by means of FFT processing, enabling zero-forcing equalisation in the frequency domain as follows:

$$X_{eq} = \frac{FFT(R)}{FFT(\mathrm{H}_{pad})} \tag{10}$$

where R represents the N samples of an OFDM symbol based on the detected start of frame (SoF) and H_{pad} represents N samples of the CIR, i.e. the vector H padded with zeros.

The method described in (5)-(10) is based on the assumption that the received signal is perfectly synchronised in time and frequency. In [4] it is shown that near-ideal synchronisation can be achieved using threshold and such technique is incorporated into the proposed method. However, it is observed that the first arriving channel tap may be missed due to severe fading, and the 2nd or 3rd tap detected as SoF. This effect degrades the performance of the proposed channel estimation technique.

In order to solve this problem, a sliding window which searches for the complete CIR is proposed. The idea is to obtain a collection of CIRs using the proposed channel estimation technique for timing points preceding the initial SoF ($\hat{d}_{init}$) indicated by timing synchronisation using [4]. The timing point that produces the maximum CIR energy is chosen as the new SoF ($\hat{d}_{new}$). This will either coincide with the first arriving channel tap or fall into the ISI-free region of the CP.

$$\hat{d}_{new} = \arg\max_{d} \left\{ \sum_{l=0}^{\lambda} \left(\left| h_{d,l} \right|^2 \right) \right\}; \quad d \in \left\{ \hat{d}_{init} - \lambda,\, \hat{d}_{init} \right\} \tag{11}$$

The search window repeats the processing of (5)-(10) to calculate the CIR for timing points preceding the initial SoF by up to a maximum of $L-1 \leq \lambda \leq G$ samples since the method in [4] can always detect a strong channel tap.

Computer simulations: Simulations are carried out using the ITU-R pedestrian B channel power-delay-profile as shown in Table 1. The simulation parameters are similar to Fixed WiMAX with FFT size $N = 256$, $N_{used} = 200$, CP length $G = 16$, carrier frequency $F_c = 3.5GHz$, subcarrier spacing $\Delta f = 15.625KHz$ and sampling rate $F_s = 4Msamples/s$. QPSK sub-carrier modulation is implemented and 5 data symbols are transmitted in each frame. 1 preamble with two identical parts in time-domain (generated using IFFT processing) is used for the proposed methods while 1 in 6 subcarriers are used as pilots for the LS and MMSE techniques. Simulation results are shown in terms of uncoded bit-error rate (BER).

Fig. 1 shows that in static channels (v=0km/h), the proposed methods achieve an accuracy similar to the ideal and significantly better than MMSE and LS techniques. This is due to its averaging of noise over time-domain samples and non-dependence on interpolation. In Fig. 2, the proposed methods maintain superiority at a pedestrian speed (v=3km/h) since the channel coherence time is much larger than the frame duration.

It is established that the complexity of MMSE is in the order of N^3 while the proposed method has a complexity in the order of G^4 wherein $G << N$.

Conclusions: We have proposed a low-complexity time-domain channel estimation technique based on preamble or training symbols. We also proposed a search window to further improve timing synchronisation and channel estimation accuracy. BER results show that the proposed method outperforms established pilot-based techniques such as MMSE in quasi-static channels. Therefore, it can be used in existing systems such as WiFi and Fixed WiMAX where receiver mobility is slow.

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References

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Figure/Table captions:

Table 1 Power Delay Profile (PDP) for ITU-R pedestrian channel B

Fig. 1 BER performance in static channel

Fig. 2 BER performance at pedestrian speed

Table 1

Channel Tap #	**Delay (in *ns*)**	**Relative Power (in dB)**
1	0	0
2	200	-0.9
3	800	-4.9
4	1200	-8.0
5	2300	-7.8
6	3700	-23.9

Figure 1

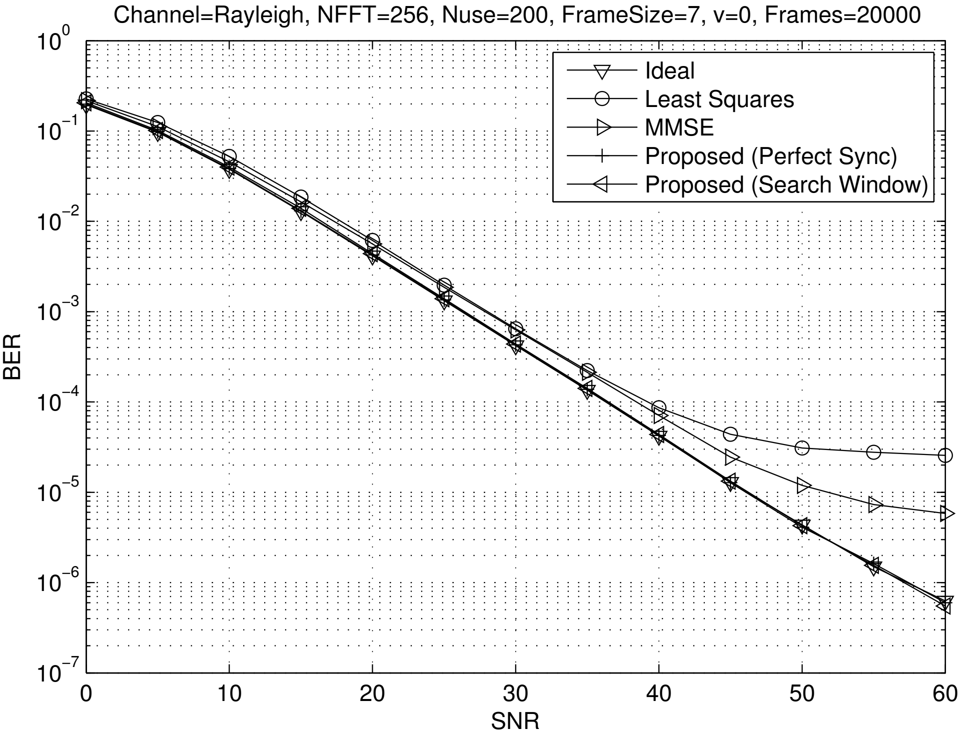
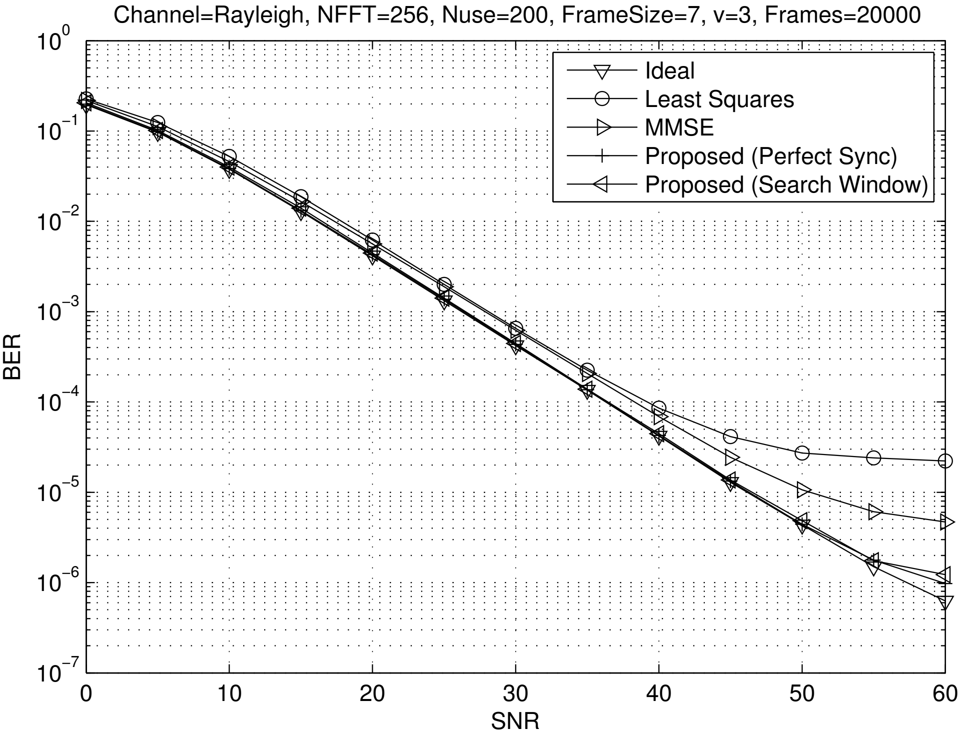

Channel=Rayleigh, NFFT=256, Nuse=200, FrameSize=7, v=0, Frames=20000
BER
SNR
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0
10
20
30
40
50
60
Ideal
Least Squares
MMSE
Proposed (Perfect Sync)
Proposed (Search Window)

Figure 2


Channel=Rayleigh, NFFT=256, Nuse=200, FrameSize=7, v=3, Frames=20000
Ideal
Least Squares
MMSE
Proposed (Perfect Sync)
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BER
SNR
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0
10
20
30
40
50
60