Non-Pilot-Aided Timing Offset Estimation for OFDM Systems with Frequency Diversity

*Hyun Yang **Young-Hwan You

Sejong University

Abstract

This letter deals with non-pilot-aided symbol timing estimation methods in an orthogonal frequency division multiplexing (OFDM) system. To do this, OFDM system uses a frequency diversity scheme over two consecutive data symbols. Our approach can be viewed as an expansion of Schmidl's and Minn's correlation methods. Using the OFDM signal equipped with frequency diversity, however, symbol timing is accurately estimated without additional training symbol and a second-order diversity gain is achieved.

1. INTRODUCTIONS

Orthogonal frequency division multiplexing (OFDM) systems are sensitive to symbol timing error and carrier frequency offset [1]. The wrong timing estimation results in inter-channel interference (ICI) and inter-symbol interference (ISI) [2]. Therefore, timing estimator is important part of OFDM system to estimate a accurate timing offset in multipath-fading channel. Schmildl's method uses a preamble containing the two same halves for timing offset estimation [3]. This method gives simple and robust estimates for symbol timing and carrier frequency offset. However, the timing metric of Schmidl's method has a plateau. To reduce the uncertainty due to the timing metric, Minn proposed a method as modification to Schmidl's [4]. From [3][4], Schmidl's and Minn's methods are algorithms of the pilot-aided synchronization methods. To obtain a good efficiency, the ratio of the number of overhead bits for synchronization to the number of message bits must be kept to a minimum, and low-complexity algorithms are needed [3].

This letr deals with a low-complexity non-pilot-symbol aided timing estimator for OFDM systems. OFDM signal by using a frequency diversity coupled with a cyclic time shift enables non-pilot-aided estimation. We can find that OFDM system with frequency diversity is shown to contain sufficient information to synchronize the system without the aid of training symbols.

2. Non-Pilot-Aided TIMING ESTIMATOR

A. OFDM Symbol with Frequency Diversity

We consider an OFDM system employing N subcarriers and N_g cyclic prefix (CP) samples. In this letter, the N-dimensional OFDM symbol at the l-th symbol period is denoted by $S_l = [X_l X_{l+1}]$ with each component $X_{l+m} = [X_{l+m}(0)\ X_{l+m}(1)\ X_{l+m}(N/2-1)](m=0,1)$ of $N/2$-dimensional vector of the OFDM symbol and during the next $(l+1)$-th symbol period $S_{l+1} = [X_{l+1} X_l]$ is transmitted. Intuitively, we can expect that the OFDM achieves the same diversity gain as the one developed in [5]. From the transmitted signals S_l and S_{l+1}, we can see that S_{l+1} is the $N/2$-th cyclic-shifted version of S_l in frequency domain.

To avoid timing metric plateau, the $(l+1)$-th symbol in time domain denoted by $s_{l+1}(n)$ is designed to be the $N/2$-th cyclic shifted version of the l-th symbol $s_l(n)$. Using this formulation, $s_l(n)$ for $0 \le n \le N-1$ is given by

$$\begin{aligned} s_l(n) &= \frac{1}{\sqrt{N}} \sum_{k=0}^{N/2-1} X_l(k) e^{j2\pi kn/N} \\ &+ \frac{1}{\sqrt{N}} \sum_{k=N/2}^{N-1} X_{l+1}(k-N/2) e^{j2\pi kn/N} \\ &= x_l(n) + x_{l+1}(n) \end{aligned} \tag{1}$$

Similarly, the N-point inverse fast Fourier transform output sequence of $s_{l+1}(n)$ can be expressed as

$$\begin{aligned} s_l(n) &= \frac{1}{\sqrt{N}} \sum_{k=0}^{N/2-1} X_{l+1}(k) e^{j2\pi k(n+N/2)/N} \\ &+ \frac{1}{\sqrt{N}} \sum_{k=N/2}^{N-1} X_l(k-N/2) e^{j2\pi k(n+N/2)/N} \\ &= x_l(n+N/2) e^{j\pi n} + x_{l+1} e^{-j\pi n}(n) \\ &= s_l(n+N/2) e^{j\pi n}. \end{aligned} \tag{2}$$

From (2), the $(l+1)$-th OFDM symbol in the time domain can be easily implemented by simply multiplying $s_{l+1}(n+N/2)$ by $e^{j\pi n}$ without IFFT operation. In the ordinary OFDM system, the IFFT is used every one OFDM symbol. In the OFDM structure with frequency diversity, we can see from (2) that the phase is untouched for even-indexed OFDM samples of$s_{l+1}(n)$ when compared to $s_l(n)$, while only phase rotation by multiples of π is observed for odd-indexed OFDM samples. Therefore, the transmitted symbol $s_{l+1}(n)$ at the $(l+1)$-th period can be implemented without any multiplication, i.e., the IFFT is used once every two OFDM symbols.

At the receiver, the part of the received signal is given by

$$y_l(n) = \sum_{i=0}^{L} h(i) s_l(n-i-\tau) e^{j2\pi(n \cdot N_c)\Delta/N} + w_l(n) \quad (3)$$

where $N_c = N + N_g$, $\{h(i)\}_{i=0}^{L}$ denotes the channel impulse response with maximum delay spared L, τ is the integer-valued unknown arrival time of a symbol, Δ is the frequency offset normalized by carrier spacing, and $w_l(n)$ is the samples of zero-mean complex AWGN.

B. Proposed Estimation Method A

The proposed estimator is based on Schmidl's sliding window method and uses the correlation between two consecutive received information-bearing OFDM signals $y_{l+1}(n)$ and $y_{l+1}(n)$. To avoid timing metric plateau, two correlation windows of length $(N/2+N_g)$ samples are separated by $(N/2+N_g)$ samples. So, this correlation methods introduced by two-symbol repetition coupled with the cyclic time shift. In our work, correlation function denoted by $P_A(d)$ and received energy denoted by $R_A(d)$ are respectively defined as

$$P_A(d) = \sum_{k=0}^{N_c-1} (-1)^k y_{l(d+k+N-N_c)} y^*_{l-1}(d+k-N_g) \quad (4)$$

and

$$R_A(d) = \sum_{k=0}^{N_c-1} |y_{l+1}(d+k-N_g)|^2 \quad (5)$$

where d is time index of the first signal in the window for symbol timing estimation and $N_c = N/2+N_g$. Then the timing metric $M_A(d)$ is given by [4]

$$M_A(d) = \frac{|P_A(d)|^2}{R_A^2(d)}. \quad (6)$$

C. Proposed Estimation Method B

To improve the accuracy of estimation, here, we propose another correlation based method, which is still low-complexity and can be viewed as an extension of Minn's training symbol method[4]. In this approach, $P_B(d)$ and $R_B(d)$ are defined as

$$P_B(d) = P_A(d) + \sum_{k=0}^{N_c-1} (-1)^k y_{l(d+k-N_g)} y^*_{l-1}(d+k+N-N_c) \quad (7)$$

and

$$R_B(d) = R_B(d) + \sum_{k=0}^{N_c-1} |y_{l+1}(d+k+N-N_c)|^2. \quad (8)$$

Substituting Eqns. (7)-(8) into $|P_B(d)|^2/R_B^2(d)$ yields a timing for this approach. When compared to the proposed method A, however, the complexity of the proposed method B is about twice.

D. Computational Burden

Table 1
Complexity Comparison of Various Timing Estimators

Estimator	No. of real additions	No. of complex additions	No. of complex multiplications
Schmidl	$N/2$	$N/2$	$N+1$
Minn A	$N_g'(N+1)$	$N_g' \cdot N/2$	$N_g'(3N/2+1)$
Minn B	$N/2$	$N/2$	$N+1$
Proposed A	$N/2+N_g$	$N/2+N_g$	$N+2N_g+1$
Proposed B	$N+2N_g$	$N+2N_g$	$2N+4N_g+1$

As for the computational complexity issue, we consider the computing of timing metric. The detailed computational complexity is listed in Table 1 ($N_g' = N_g + 1$) . Schmidl's method, Minn's method B, and two proposed methods require one additional real multiplication and real division, while both Minn's method A requires N_g' real multiplication and real division operations. The proposed method A requires additional $4N_g$ operations compared to Schmidl's and Minn's method B. And the proposed method A provides approximately half-time reduction of the computational burden over the proposed method B. However, the complexity of proposed method B is absolutely lower than that of Minn A method.

3. RESULTS AND DISCUSSIONS

In this section, to verify the effectiveness of the proposed estimator, we compare mean and MSE of both ordinary and proposed estimators. OFDM system with $N=256$ and $N_g=32$ is considered. The performance of the proposed estimators has been compared to three reference estimators: 1) Schmidl's method with 90% maximum points averaging[3], 2) Minn's sliding window method (Minn A), and 3) Minn's training symbol methods (Minn B)[4]. Here, we assume that the channel is modeled as L = 15 paths equal tap spacing of two samples and path gains given by

$$\Omega_l = e^{-l\delta}\left(\sum_{k=0}^{L-1} e^{-k\delta}\right)^{-1}, \qquad 0 \le l \le L \quad (9)$$

where $\delta \ge 0$ is the rate of average power decay and we choose δ such that the ratio of the first Rayleigh fading tap to the last Rayleigh fading tap is 20 dB.

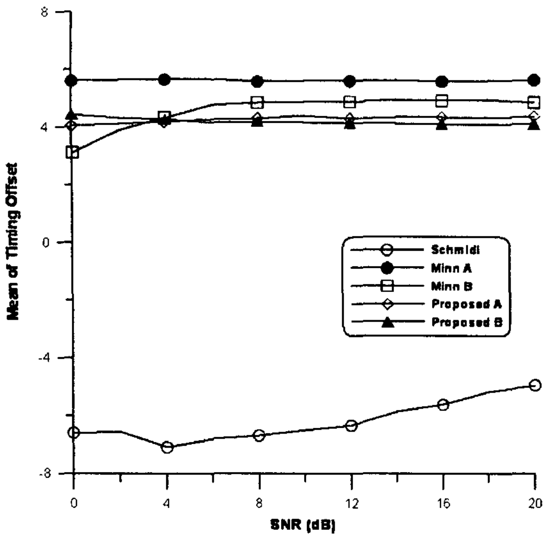

Fig 1. Mean of estimators in a multipath channel

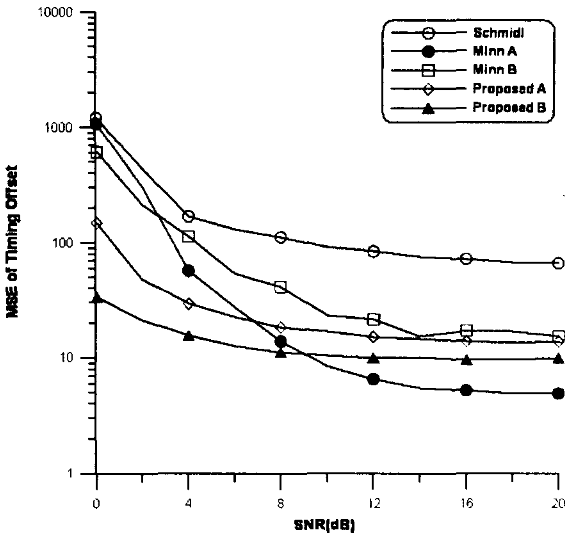

Fig 2. MSE of estimators in a multipath channel

Fig. 1 and Fig. 2 show the means and variances for the timing offset estimators, respectively. In Fig. 1, mean of proposed methods are near the zero-timing offset more than that of Schmdl's and Minn's methods, which says that reduction of timing metric plateau makes more accurate estimation. In Fig. 2, we can observe that the proposed timing offset estimators have much smaller MSE than other estimators. When compared to Minn's method B, the proposed method A gives a better MSE performance with a slight increase of complexity, while the MSE of proposed method B is lower than that of Minn's method A with complexity reduction of 96%. Additionally, we find that the proposed estimators give a good estimation performance without training sequence at especially low SNR.

4. CONCLUSIONS

In this letter, two timing offset estimation schemes which do not require the transmission of pilot symbols were developed for OFDM systems. From the presented results, we can see that the proposed methods give very accurate estimates of OFDM symbol timing with reduced complexity. At the same time, the proposed OFDM system can get frequency diversity gain. Therefore, the proposed estimators are more favorable for the initial timing synchronization of OFDM system.

참고문헌

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