Timing and Delay Spread Estimation Scheme in OFDM Systems

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and Jin-Tong Chang

Abstract — *In this paper, a scheme for symbol timing estimation and delay spread estimation using subblock correlation is proposed in the OFDM systems. The subblock correlation between the cyclic prefix and data symbol is applied to estimate symbol timing and the length of delay spread. Under a multipath fading channel referred to the OFDM multipath channel model in the standard of IEEE 802.11a/g WLAN, the results show that performance with the proposed scheme is better than that with Beek's scheme. In addition, the length of the delay spread could be estimated in the proposed scheme. Hence, in order to increase the bandwidth efficiency, the length of cyclic prefix could be adaptively assigned in the OFDM system*[1].

Index Terms —OFDM Systems, Subblock Correlation, Timing Estimation, Delay Spread Estimation.

I. INTRODUCTION

Orthogonal frequency division multiplexing (OFDM) technique in wireless communication becomes significant because it could provide a high data rate transmission. The bandwidth efficiency of OFDM is another advantage for the band limited communication system [1]-[5]. OFDM technique has been applied into many digital transmission systems such as digital audio broadcasting (DAB) system, digital video broadcasting terrestrial TV (DVB-T) system, asymmetric digital subscriber line (ADSL), wireless local area network (WLAN), broadband wireless access (BWA) network and ultra-wideband (UWB) systems [1]-[5]. Hence, OFDM is a promising technique in the current wireless communication system.

However, using OFDM technique, there are some difficulties such as synchronization, PAPR, interference cancellation, channel estimation [3]-[9]. The knowledge of symbol timing is required for demodulation in OFDM systems [1], [2], [6], [7]. At the receiver, the symbol boundaries and the optimal timing instants are required to minimize the effects of inter-symbol interference (ISI). In the OFDM systems, both data-aided and non-data-aided synchronization algorithms have been proposed previously [6], [7], [10]-[14]. In the data-aided scheme, at the receiver, the symbol synchronization could be implemented with the aid of the dedicated training symbols or pilot symbols [7], [10], [11], [13]. The frame synchronization using the designed train symbol has been proposed [7]. Reliable frame synchronization could be obtained under a low signal-to-noise (SNR) environment. Based on the pseudo-noise (PN) sequence preambles, OFDM synchronization gives a better detection in terms of the low false error and low missing error [10]. Based on the constant envelope preamble, the synchronization algorithm exploits the correlation property of the PN sequence and the two identical parts of the preamble to estimate the timing offset. It enhances the accuracy of the timing offset estimation [11]. Although the data-aided algorithms could provide a better estimation on symbol synchronizations, it suffers the bandwidth efficiency.

To increase the bandwidth efficiency of the OFDM system, non-data-aided algorithms have been proposed [6], [12], [14]. Within the non-data-aided algorithms, the cyclic property of the guard interval could be employed for the symbol synchronization without any training symbol in the OFDM systems. Among those non-data-aided algorithms, the estimator exploits the second-order cyclostationarity of the received signals and, then, it obtains the information of symbol-timing offset by the cyclic correlation [12]. On the other hand, the maximum likelihood (ML) estimator proposed by Jan-Jaap van de Beek uses the correlation between the cyclic prefix and the OFDM symbol to find the symbol timing under an additive white Gaussian noise (AWGN) channel [6]. It uses the redundant information contained within the cyclic prefix. The results show that Beek's ML-based estimator could have a lower error variance when the number of cyclic prefix samples is larger. However, the straightforward implementation of the correlator results in high hardware complexity and high power consumption to perform complex additions for each correlator output. In [14], only the sign bits of correlator results are used to estimate the frame timing and the frequency offset, and for the purpose of reducing complexity and power consumption.

In this paper, a scheme applying the subblock correlation with a window length B (will be shown later) is proposed to estimate the symbol timing and the length of delay spread. In this paper, the multipath fading channel is referred to the OFDM multipath channel model in the IEEE 802.11a/g wireless LAN standard. The channel is assumed to be a slow fading channel. With the estimated delay spread, the length of cyclic prefix could be adaptively assigned to reduce the system overhead and, then, increase the bandwidth efficiency of the OFDM system. In the following section, the OFDM system model and multipath channels model are presented. In Section III, the timing and delay spread estimation scheme applying the subblock correlation is proposed. The performance of the proposed scheme is shown in Section IV. Finally, a conclusion is given in Section V.

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II. THE SYSTEM MODEL AND THE MULTIPATH CHANNEL MODEL

An OFDM signal contains a sum of subcarriers that are phase shift keying (PSK) or quadrature amplitude modulation (QAM) modulation. Each parallel data transmission is modulated by different carrier frequencies using PSK or QAM scheme. Besides, in order to reduce the complexity of OFDM modem implementation, the inverse fast Fourier transform (IFFT) and the fast Fourier transform (FFT) are employed to replace the banks of sinusoidal generator for the modulation and demodulation. In general, an OFDM system at least contains the function of parallel transmission, signal mapping and IFFT/FFT. Fig. 1 illustrates the block diagram of the baseband, discrete-time FFT-based OFDM systems model. PSK/QAM modulated data are generated in each parallel data and, then, those data are modulated by an IFFT on N-parallel subcarriers. With a cyclic prefix, the complete OFDM symbol is transmitted over a discrete-time channel. At the receiver, the data are retrieved by a FFT and, then, demapped with corresponding scheme to obtain the estimated data.

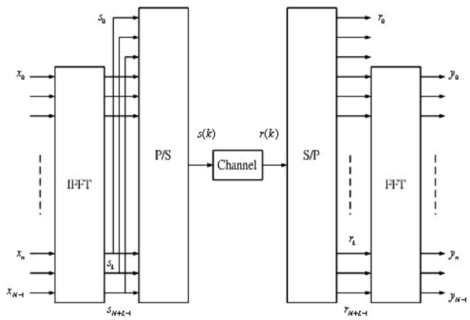

Fig. 1. The baseband FFT-based OFDM systems

An OFDM discrete-time baseband signal can be expressed as

$$s_i(n) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} x_i(k) e^{j\frac{2\pi kn}{N}}, \quad 0 \le n \le N-1, \tag{1}$$

where $s_i(n)$ represents the n^{th} sample of the i^{th} OFDM symbol, N denotes the number of subcarriers (which is also the FFT window size) and $x_i(k)$ represents the data of the k^{th} subcarrier in the i^{th} symbol interval. With a cyclic prefix, the complete OFDM symbol is transmitted over a discrete-time channel. The length of cyclic prefix is denoted as L. The OFDM symbol with a cyclic prefix is depicted in Fig 2.

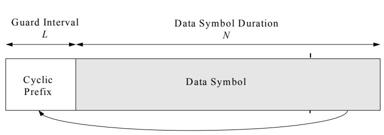

Fig. 2. OFDM symbol with a cyclic prefix

In this paper, the multipath channel is referred to the OFDM multipath channel model in the IEEE 802.11 wireless LAN standard [15]. The kth channel impulse response is given by

$$h_k = N\left(0, \frac{1}{2}\sigma_k^2\right) + jN\left(0, \frac{1}{2}\sigma_k^2\right), \tag{2}$$

where $N(0, \sigma_k^2/2)$ is a Gaussian random variable with zero mean and variance σ_k^2, where $\sigma_k^2 = \sigma_0^2 \cdot e^{-k \cdot Ts/TRMS}$ and $\sigma_0^2 = 1\text{-}e^{-Ts/TRMS}$. The power delay profile is assumed to be exponentially decaying. Besides, the maximum delay spread is assumed to be smaller than the length of cyclic prefix.

Before demodulating the received OFDM signal, the receiver has to make the symbol and frequency synchronization. Thus, the receiver should remove the cyclic prefix. However, the synchronization should be done to remove the prefix. Once, timing information provided by the synchronization algorithm, one could exactly remove the prefix and, then, use FFT to extract the transmitted data. When the estimated symbol timing is determined as the sample within the guard interval, the extracted data symbol is a cyclic shift of the original data symbol. With a linear phase rotation, the data could be recovered. However, the estimated symbol timing is located at the sample within ISI region listed in Fig. 3, the extracted data symbol is distorted by the interference caused by the neighboring symbols. The ISI region means the guard interval region suffered by multipath delay spread. In order to avoid the ISI effect, the timing estimation and the delay spread estimation are the most important works in the OFDM systems. Actually, the carrier frequency synchronization algorithm in [16], for instance, could be used to compensate the effect of frequency offset. In this study, the carrier frequency synchronization is not considered. In the following section, a scheme for timing estimation and delay spread estimation using the subblock correlation scheme is proposed.

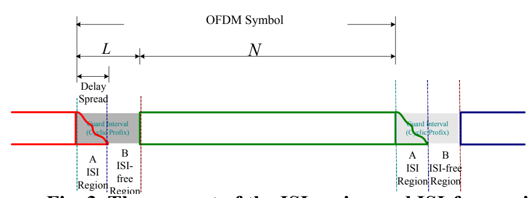

Fig. 3. The concept of the ISI region and ISI-free region

III. TIMING AND DELAY SPREAD ESTIMATION USING SUBBLOCK CORRELATION

ML-based timing estimation proposed by Jan-Jaap van de Beek uses the correlation between the cyclic prefix and the data symbol to get the symbol timing [6]. In Beek's scheme, the complete cyclic prefix is considered to estimate the symbol timing. However, the partial samples within the cyclic prefix are suffered by the delay spread caused by multipath fading. It is easy to make erroneous judgments in timing estimation. The estimated timings in Beek's scheme are almost located at the sample around the actual symbol timing. The proposed scheme uses the subblock correlation to estimate the symbol timing and the length of delay spread. Without the use of the whole cyclic prefix, the smaller sized subblocks are applied to compute the correlation in the proposed scheme. The length of the observation interval ψ is equal to $2N+L$. In the scheme, the subblock size is equal to B and the number of subblock in the OFDM symbol is equal to

$(N+L)/B$. With the window of subblock length B, .the proposed scheme computes the correlation block by block to obtain the timing and delay spread. The subblock correlation is calculated by the samples within the subblocks that are apart from the N/B. Fig. 4 shows the concepts of the subblock correlation in the timing estimation scheme. Besides, under a slow fading channel, moving average method could be applied in the proposed scheme to obtain a better estimation.

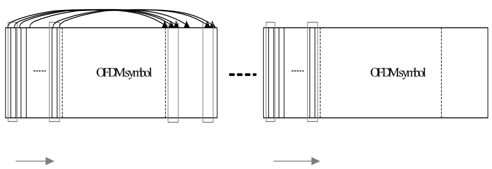

Fig. 4. The concept of the subblock correlation timing estimation method

Let $r_i(n)$ be the received signal under an AWGN channel, the received signal could be written as

$$r_i(n) = s_i(n-\theta)e^{j\frac{2\pi}{N}\varepsilon(n-\theta)} + w_i(n), \tag{3}$$

where $s_i(n)$ is the transmitted signal for the ith OFDM symbol in Eq. (1), N denotes the number of subcarriers, θ and ε are the timing shift and the carrier frequency offset respectively, and $w_i(n)$ is an Gaussian noise. The samples within the observation interval ψ could be expressed as

$$\Psi = [r(i), r(i+1), ..., r(i+2N+L-1)]_{1\times(2N+L)}, \tag{4}$$

where the $r(i)$ is the i^{th} sample in the received signal. In the proposed scheme, the samples within the observational interval ψ are segmented into $(2N+L)/B$ subblocks. Each subblock $b(m)$ could be expressed as

$$b(m) = [r(B(m-1)+i), r(B(m-1)+i+1), ..., r(B(m-1)+i+B-1)]_{1\times B},$$
$$m = 1, 2, ..., \frac{2N+L}{B}. \tag{5}$$

Then, the samples within the observational interval could be rewritten as

$$\Psi = [b(1), b(2), ..., b(\frac{2N+L}{B})]. \tag{6}$$

The correlation coefficients $\rho(\cdot)$ between two corresponding pair-wise subblocks is

$$\rho(d) = \frac{b(d)\cdot b^*(d+\frac{N}{B})}{\|b(d)\|\cdot\left\|b(d+\frac{N}{B})\right\|},$$
$$= \frac{\sum_{i=0}^{B-1} r(d\cdot B+i)r^*(d\cdot B+i+N)}{\sqrt{\sum_{i=0}^{B-1}|r(d\cdot B+i)|^2}\sqrt{\sum_{i=0}^{B-1}|r(d\cdot B+i)|^2}},$$
$$m = 1, 2, ..., \frac{N+L}{B}. \tag{7}$$

The proposed algorithm uses the slide windows to calculate the correlation coefficients block by block. Two operations of subblock correlation method can be used to estimate the timing. One possibility is to choose the maximum subblock correlation value as the estimated timing position. In the observation region, the correlation coefficients $\rho(d)$ of subblock $b(d)$ with the maximum value is chosen, and, then, the symbol timing could be determined with the corresponding index of the first sample within the subblock $b(d)$. Another is to obtain the threshold in advance. The estimated timing could be determined if the difference between two neighboring subblock correlations is smaller than the desired threshold. In this paper, the correlation coefficients $\rho(d)$ of subblock $b(d)$ with the maximum value is chosen in the observation region, and, then, the symbol timing could be determined with the corresponding index of the first sample within the subblock $b(d)$. Besides, the ISI region and ISI-free region could be discriminated with a rapid ascent of the subblock correlation value. Hence, with a desired threshold in the proposed subblock correlation, the length of the delay spread could be determined. Based on the proposed algorithm, simulations are given in the following.

IV. SIMULATION RESULTS

Simulations for the proposed algorithm are performed over an AWGN channel and multipath fading channel. In each simulation with 10^6 running OFDM symbols, it is assumed modulation type to be 16-QAM, the bit rate to be 20 Mbps, the number of subcarrier to be 1024, the length of cyclic prefix to be 256 and subblock size to be 16. In the multipath channel, the power delay profile is assumed to be exponentially decaying. Besides, the maximum delay spread is assumed to be smaller than the length of cyclic prefix. The simulation parameters are listed in Tab. 1.

TABLE. 1.
SIMULATION PARAMETERS

Parameters	Values
Modulation Type	16 QAM
Required Bandwidth	5 MHz
Data Rate (Bit Rate)	20 Mbps
Carrier Frequency	5 GHz
Maximum Doppler Shift	$\approx$ 0 Hz
Number of Subcarriers	1024
Sampling Duration	0.2μs
Symbol Duration	204.8μs
The Samples within Cyclic Prefix	256
Duration of Cyclic Prefix	51.2μs
The path number of Multipath Channel	15 path
Subblock Size	16

The performance of the estimators is evaluated by the mean-squared error (MSE) of the estimator. Fig. 5 and Fig. 6 show the performance of the subblobk correlation scheme and Beek's scheme in AWGN channel and multipath fading channel. Beek's ML-based estimation has the better performance in AWGN, while it is serious under a multipath fading channel because the partial samples within in the cyclic prefix are suffered by the delay spread caused by multipath fading. The simulation result shows that the proposed subblock scheme has a better performance under the multipath fading channel.

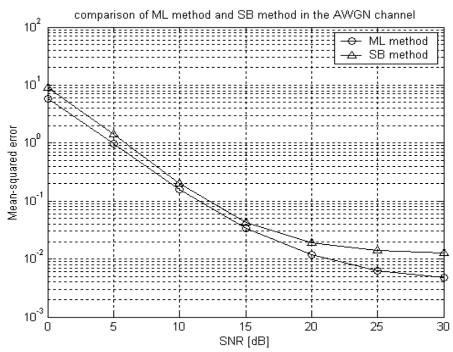

Fig. 5. Mean-square error for Beek's scheme (ML method) and the proposed subblock correlation scheme (SB method) under an AWGN channel.

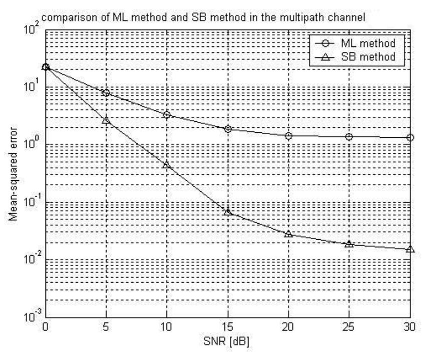

Fig. 6. Mean-square error for Beek's scheme (ML method) and the proposed subblock correlation scheme (SB method) under a multipath channel

Fig. 7 shows the subblock correlation values within the cyclic interval when the subblock size is assumed to be 16. The actual value of delay spread is located at 128th sample that is equal to half of the cyclic prefix length. Hence, the estimated delay spread is the first sample within in the ninth block. In the figure, the interval of first eighth blocks is called as the ISI region. The resolution of the subblock correlation is equal to the length of subblock and the estimated length of the delay spread is slightly large than the actual one. When the length of the delay spread is not a multiple of the subblock size, there may be wrong estimation of the ISI region using only one time estimation. With a variable subblock length, a more accurate length of the delay spread could be obtained. In Fig.8, the delay spread could be estimated exactly in the case of SNR=15dB and B=16 in the simulation.

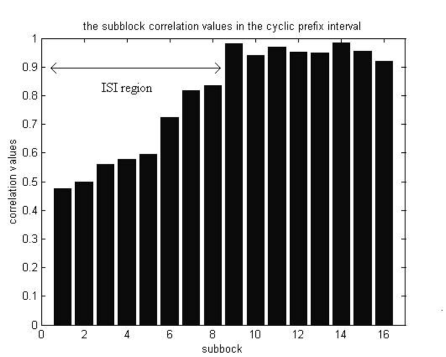

Fig. 7. The correlation results with the subblock size 16

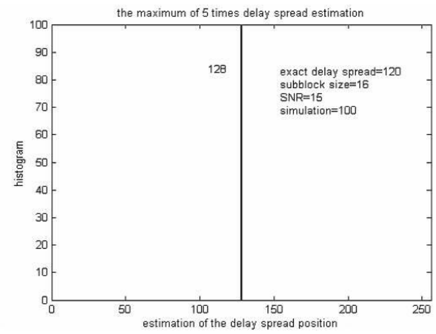

Fig. 8. The histogram of the estimated delay spread

V. CONCLUSION

In this paper, the symbol timing estimation and delay spread estimation using the subblock correlation is proposed. The results show that estimator MSEs with the proposed scheme are better than that with Beek's ML estimation scheme under a multipath environment. The information of the delay spread also could be provided in the proposed scheme. The resolution of the subblock correlation is equal to the length of subblock and the estimated length of the delay spread is slightly large than the actual one. With a variable subblock length, an accurate length of the delay spread could be obtained. Under a slow fading channel, the length of the cyclic prefix could be adaptively adjusted to increase the bandwidth efficiency in the OFDM system.

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