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Two symbol timing estimation methods using Barker and Kasami sequence as preamble for OFDM-based WLAN systems

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ABSTRACT

The estimation of the exact point for the start of the symbol is significant as the orthogonal frequency division multiplexing (OFDM) systems are very sensitive to timing errors. In the IEEE 802.11a wireless local area network (WLAN), each data packet starts with a preamble consisting of ten short training symbols followed by two long training symbols. The timing metric is computed through autocorrelation of the received samples and their delayed copies. When the preambles are known to the receiver, the timing metric is obtained by crosscorrelation of the received samples with the locally generated samples. The correlation peak of the timing metric indicates the correct symbol time. The symbol timing synchronization schemes in IEEE 802.11a WLAN systems use short training symbols to estimate a coarse symbol time via autocorrelation and then use long symbols to find a fine symbol time via crosscorrelation. In this paper, Barker and Kasami codes are proposed to be used as preambles for timing estimation in OFDM WLAN systems. Timing estimation makes use of correlation of preamble. So preamble with good autocorrelation property has to be chosen. The proposed scheme develops a simple preamble structure and gives more accurate estimate of symbol timing.

1. Introduction

Orthogonal frequency division multiplexing (OFDM) is one of the attractive broadband wireless communication technologies. The main advantage of OFDM is its high data rate and its robustness to multipath fading channel. Thus, OFDM is used in wireless communication and broadcasting systems such as wireless local area network (WLAN) systems, WMAN systems, digital video broadcasting (DVB) and digital audio broadcasting (DAB).

The main disadvantage of OFDM is its sensitivity to timing errors. If the estimated starting position of the OFDM symbol is within the data interval, inter symbol interference (ISI) takes place causing dispersion of the signal. This is called improper symbol timing. It leads to large bit errors at the receiver and affects detection part. The channel assumed here is the multipath fading channel. So the delay in the received signal leads to sampling of frame at the incorrect timing instant. This leads to timing offset and causes rotation of constellation points at the receiver side. But the timing offset can be eliminated if the symbol timing is estimated correctly.

In this paper, two timing offset estimation methods based on Barker and Kasami sequence as preambles are proposed for OFDM systems in WLAN environment. The simulation result shows that of the two methods proposed, the algorithm using Kasami sequence as preamble is simple and accurate in symbol timing estimates even in the worst channel conditions.

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Many algorithms were proposed in the literature to solve timing estimation problem. Jan-Jaap et al. [1] proposed that redundant information contained within the cyclic prefix enables the timing estimation without additional pilots. Simulations done showed that the time estimator can be used in an acquisition mode of WLAN system. Lee and Cheun [2] described the new symbol timing recovery algorithm for OFDM-based systems for which supplementary pilot signals were not required. Schmidl and Cox [3] proposed the first algorithm for timing estimation method. The preamble that was employed consisted of two repetitive patterns. But the timing metric had a plateau which resulted in uncertainty of estimating the correct timing instant. This led to large mean square errors (MSE). Tufvesson et al. [4] discussed about using repeated short pseudo noise sequences (PN-sequences) for a fast and reliable time synchronization for packet-based orthogonal frequency division multiplex (OFDM) systems. Minn et al. [5] proposed a new preamble structure and calculated timing metric differently. Although the Minn's method reduced the plateau, there were lots of small peaks associated with the plateau. Minn's timing estimation variance was quite large in ISI channels. This method also lacked clarity in identifying the exact starting symbol time instant. In WLAN the physical layer modulation technique conforms to the OFDM specifications of IEEE 802.11a [6]. Yang et al. [7] specified a timing recovery algorithm for OFDM system. Larsson et al. [8] proposed a joint symbol timing and channel estimation for OFDM-based WLANs. Park et al. [9] proposed three symbol synchronization schemes based on cyclic extension preceding OFDM symbol. Later Park et al. and Ren et al. [10,12] proposed new preamble structures and synchronization methods to obtain sharper timing metric. However, both methods had some side lobes. Bo et al. [11] explained the symbol synchronization technique in OFDM systems. Yong Wang et al. [13] proposed a novel scheme for symbol timing in OFDM WLAN systems. Tiejun et al. [14,15] described a low-complexity blind symbol timing offset estimation in OFDM Systems. Choi et al. [16] discussed and simulated a timing offset estimation method for OFDM system in Rayleigh fading channel. AlfonsoTroya et al. [17] proposed a complete solution for the inner receiver of an OFDM-WLAN system based on the IEEE 802.11a standard. The three key components for their investigations on forming the inner receiver are synchronizer, channel estimator and digital timing loop. Yeonsu Kang et al. [18] proposed an algorithm to estimate the timing using a simple circular shift operation of the preamble at the receiver. This method is suitable for any OFDM systems regardless of their preamble structures. Niu and Shen [19] proposed a novel algorithm for joint blind carrier frequency offset and symbol timing offset estimation based on cyclostationarity of received signal for a 2×2 distributed MIMO-OFDM system. All the simulations in the above cited papers provide a tradeoff between estimation accuracy and computational complexity.

The algorithms for estimation can be broadly classified as data-aided and nonaided methods. For WLAN application, data aided is the most important which uses the training information of at least two consequently repeated symbols. In this paper, a comparison of the proposed symbol timing estimation and conventional methods is done. It is found that, the Kasami method not only eliminates the side lobes of Park and Ren methods but also provides accurate timing metric which has only one peak. The preamble-based synchronization using Kasami sequence provides a symbol timing recovery in a WLAN environment that is extremely robust to wireless channel impairments such as noise, multi-path and carrier frequency offset. It provides both symbol timing accuracy and low computational complexity for the worst channel conditions also.

The main objective of this paper is to construct a simple preamble structure for OFDM-based on the WLAN system and to eliminate the side lobes of the previous works.

The rest of the paper is organized as follows. Section 2 gives an overview of OFDM system model. In Section 3, IEEE 802.11a training structure is discussed. Section 4 gives a brief description of the general algorithm for timing estimation. In Section 5, the various symbol timing estimators that calculate the timing metrics are considered. In Section 6, a new proposed scheme that completely eliminates the side lobes is described. In Section 7, simulation results are shown for WLAN OFDM specifications. Section 8 covers the conclusion of the paper.

2. OFDM system model

The OFDM system model with timing estimation part at the receiver is shown in Fig. 1.

The OFDM base band signal at the transmitter is represented as

$$x(n)=\frac{1}{\sqrt{N}}\sum_{m=0}^{N-1}X(m)e^{j2\pi nm/N},\quad 0\le n\le N-1 \tag{1}$$

where n is the time domain sample index, $X(m)$ is the modulated data symbol on the mth sub carrier and N is the number of subcarriers. In order to avoid inter-symbol interference (ISI) caused by multipath channels, a cyclic prefix (CP) is appended to the OFDM symbol. After passing the signal through the multipath channel whose impulse response is $h(n)$, a signal sample $y(n)$ is given by (2).

$$y(n)=x(n)\circ h(n)\quad 0\le n\le N-1 \tag{2}$$

where $\circ$ denotes circular convolution and $h(n)$ is given by (3).

$$h(n)=\sum_{l=0}^{L-1}h(l)\cdot\delta(n-l)\quad 0\le n\le N-1 \tag{3}$$

where $h(l)$ is the complex gain of lth path and L is the Length of $h(n)$. Usually the timing offset is modeled as time delay and thus the received signal is given by (4).

$$r(n)=y(n-\varepsilon)+z(n)\quad 0\le n\le N-1 \tag{4}$$

where ε is the timing offset and $z(n)$ is the independent and identically distributed additive white Gaussian noise (AWGN) with zero mean and variance σ_z^2 [1,2].