Fine Timing and Frequency Synchronization for CMMB System

SUN Yuming, ZHANG Yanzhong, SHAO Dingrong, LI Shujian
School of Electrical Engineering, BeiHang University, Beijing, China
e-mail: *lemensym@ee.buaa.edu.cn*

Abstract: A fine timing and frequency synchronization algorithm is presented for an orthogonal frequency division multiplexing (OFDM) system used in China mobile multimedia broadcasting (CMMB). The presented algorithm could accomplish the timing and frequency offset estimation using the perfect relation of training symbols. The simulation and practice results show the new algorithm could give out fine timing synchronization and accurate frequency offset estimation over AWGN channel and multipath channel.

Keyword: OFDM; CMMB; timing synchronization; frequency offset estimation

1 Introduction

In the broadband wireless digital communication system, a primary interference of the high speed information transmission is the frequency-selective fading. The main advantage of OFDM is that it allows transmission over highly frequency-selective channels at a low receiver implementation cost [1], but a well-known problem of OFDM is its vulnerability to synchronization errors. As a result, Synchronization at the receiver is one important step that must be performed in an OFDM system [2].

[3-6] proposed some synchronization methods using training sequence. In [3,4], a symbol timing and frequency synchronization algorithm using repeated training sequence is presented. [5] proposed a specifically designed training sequence which consists of two segments of equal length where each segment is constructed from a different pseudo-noise (PN) sequence. [6] solved the synchronization acquisition problem of OFDM system in practice. The beacon in CMMB framing structure is a special training sequence [7].

In this paper, a synchronization algorithm about timing and carrier frequency estimation based on training symbols is proposed. In the CMMB beacon, two same OFDM training symbols generated by pseudo-random sequence are transmitted. So, the presented algorithm could accomplish the timing synchronization and frequency offset estimation using the perfect relation of training symbols. The simulation and practice results show the new algorithm could give out fine timing synchronization and accurate frequency offset estimation over additive white Gaussian noise (AWGN) channel and multipath channel.

2 System Model

Considering a frame of OFDM data which consists of M data symbols, the received OFDM signal with frequency and timing offset can be represented as

$$r[i,n]=\begin{cases} s[i,n-N_g],\ n\in[N_g,N-1+N_g] \\ \qquad\qquad \bigcap i\in[1,M] \\ s[i,n+N-N_g],\ n\in[0,N_g-1] \\ \qquad\qquad \bigcap i\in[1,M] \\ q[i,n],\ n\in[0,2N_t+N_g] \\ \qquad\qquad \bigcap i=0 \end{cases} \tag{1}$$

where i represents the OFDM symbols number, n represents the sampling number, N_t represents the synchronization signal length, N_g is the length of guard interval, N represents the OFDM symbol length, $q[i,n]$ is the received training sequence and $s[i,n]$ is the received data symbol.

The training sequence consists of two training symbols and one cyclic prefix. The received training sequence can be represented as (2), where θ denotes the timing offset, $N(n)$ is the additive noise, $PN(k)$ denotes the pseudo-random sequence, H_k is the k subcarrier channel frequency response, ξ represents the normalized sampling frequency offset, Δf is the normalized frequency offset.

$$
\begin{cases}
q[0,n]=\begin{cases} t[n-N_g], & n\in[N_g,N_t-1+N_g] \\ t[n+N_t-N_g], & n\in[0,N_g-1] \\ t[n-N_g-N_t], & n\in[N_t+N_g,2N_t+N_g-1] \end{cases} \\
t[n]=\dfrac{1}{\sqrt{N_t}}\sum_{k=0}^{N_t-1}PN(k)H_k\exp\{\dfrac{j2\pi kn(1+\xi)}{N_t} \\
\quad +\dfrac{j2\pi\Delta f(1+\xi)n}{N_t}+\dfrac{j2\pi k(\xi(i(N_t+N_g)+N_g)+\theta)}{N_t} \\
\quad +\dfrac{j2\pi\Delta f(i(N_t+N_g)+N_g)}{N_t}\}+N(n)
\end{cases}
\tag{2}
$$

3 Synchronization Algorithm

Considering $PN(k)PN^*(k)=1$, the correlation between the demodulated data of training sequence and the known pseudo-random sequence could be written as

$$
\begin{aligned}
\lambda(\theta,\Delta f) &= \sum_{k=0}^{N_t-1}R_p[k]PN^*[k] \\
&= \sum_{k=0}^{N_t-1}\{\frac{\sin(\pi\Delta f)}{N_t\sin(\frac{\pi\Delta f}{N_t})}\exp(-j2\pi k\theta/N_t \\
&\quad -\frac{\pi(N_t-1)\Delta f}{N_t})\}+N_p
\end{aligned}
\tag{3}
$$

where N_p is the additive white Gaussian noise because of the pseudo-random characteristics. The fast fourier transform could be used to estimate θ. As a result, the estimation of θ and Δf could be written as [8]

$$
\begin{cases}
\hat{\theta}=\arg_{\theta}\max(\|FFT\{R_p[k]PN^*[k]\}\|) \\
\theta_c=\arg_{\theta}\max\left(\left\|\sum_{n=\theta}^{n=N_t-1}r[0,n]r^*[0,n+N_t]\right\|\right) \\
f_I=\arg_{\Delta f}\max(\|\lambda(\hat{\theta},\Delta f)\|) \\
f_F=-\dfrac{1}{2\pi}\angle(\sum_{n=\hat{\theta}+x}^{n=N_t-1}r[0,n]r^*[0,n+N_t])
\end{cases}
\tag{4}
$$

where $\hat{\theta}$ is the fine estimation of θ, x represents the number of channel paths, f_I is the integral frequency offset estimation of Δf, f_F is the fractional frequency offset estimation of Δf, θ_c is the coarse timing estimation of θ, $FFT\{\}$ denotes the fast fourier transform.

The new algorithm could implement as follows:

1) Estimate the coarse estimation of timing offset using (4).

2) Demodulate the second training symbol of training sequence by the fast fourier transform.

3) Frequency searching is applied to the fine timing and integral frequency capture, according to (4).

4) By means of (4), the fractional frequency offset estimation is realized.

5) Estimate the fine timing position use (4) and repeat 4) to track the OFDM signal.

4 Simulations

We use Monte Carlo simulations to evaluate the performance of the algorithm in CMMB system [8]. Suppose the simulation parameters as follow:

1) The 8M mode of CMMB would be used in the simulations. The baseband width is 10 MHz. In the beacon, pseudo-random sequence is modulated by the 2048 point inverse fast fourier transform. There are 1536 data sub-carriers and 512 virtual sub-carriers. As a result, the real baseband width is about 8 MHz. The guard interval length is 24.

2) The frequency offset is 3.24240625 KHz which is more than one sub-carrier interval about 801 Hz.

3) The pseudo-random sequence is m sequence which code length is 2047.

4) The signal is transmitted in AWGN, multipath A and B channel respectively. From figure 1, multipath A channel is consist of 5 paths. The delay of each path is 0, 3, 5, 7 and 11.The gain of each path could represent as hi=exp{-τi/2}.where τi is the delay of the i path, hi is the gain of the i path. The delay of multipath B channel path is the same as A. The gain of each path is 1, 0.891, 0.354, 0.316 and 0.1. It is obviously that the main paths of multipath B channel are more than A about 1 path, so the inter-symbol interference in multipath B channel is severer than A.

5) In each simulation, 1000 time slots are used. One slot includes 1 beacon and 53 OFDM data symbols.

The simulation results show the timing error is less than 1 sampling point and the frequency estimation error

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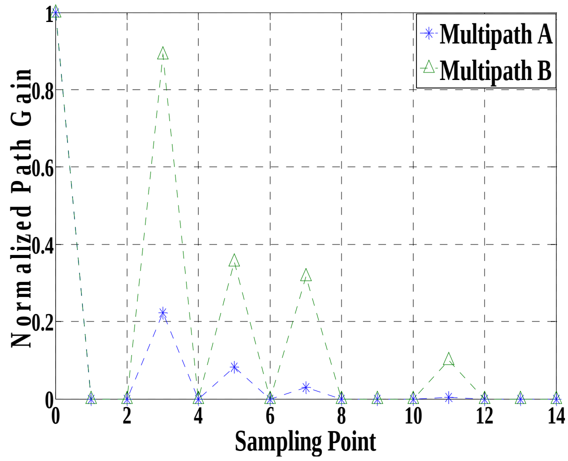

Figure 1. Multipath channel

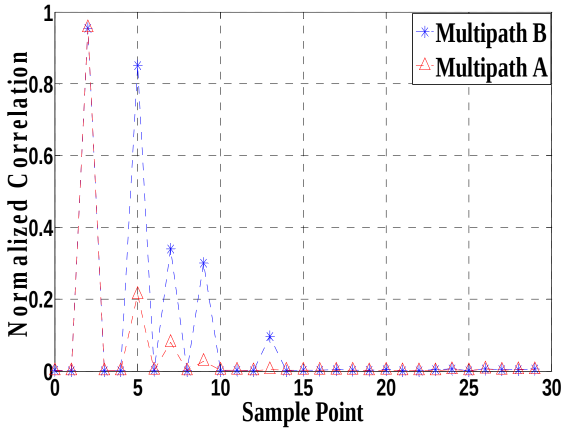

Figure 2. Estimate the channel paths when SNR is 20 dB

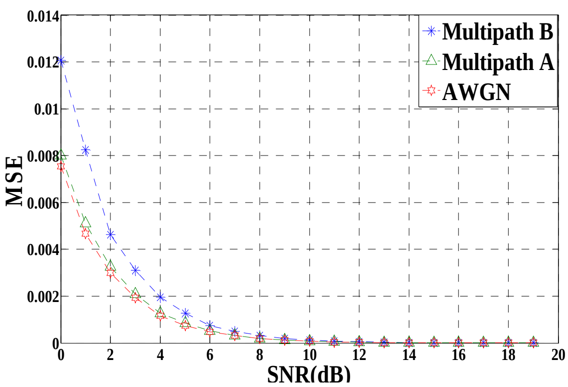

Figure 3. The MSE of frequency estimation

is less than 1Hz. From figure 2, the new algorithm could estimate the amount of multipath. From figure 3, when signal-to-noise (SNR) ration is more than 10 dB, the mean-square error (MSE) of AWGN channel is almost the same as multipath channel.

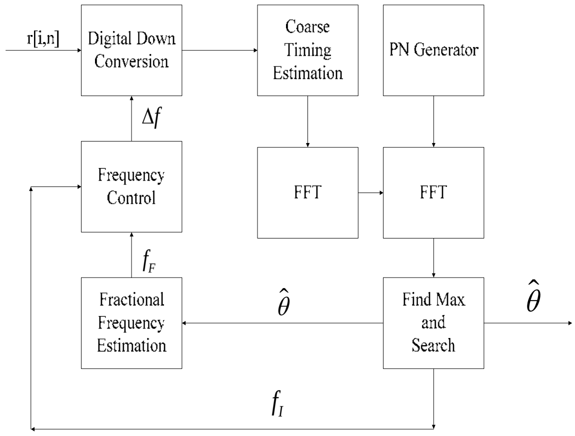

Figure 4. Implement flow chart

5 Practice

The new algorithm had already been implemented in practice, from figure 4. Firstly, the received signal converted to baseband signal with frequency offset by the digital down conversion block. Secondly, estimate the approximate timing position using the coarse timing estimation block. Thirdly, compute the correlation by the FFT block which could use the same FFT block in FPGA because of the different working time. Finally, estimate the fine timing position and frequency offset.

To calculate the timing estimation mean-square error, a counter has been designed to record the amount of point between two correlation peaks. Standard signal has been generated by MATLAB which the signal-to-noise ration of is from 0 to 30 dB. The signal is sent by vector signal generator. Acquire the counter outcome in each signal-to-noise ration using ChipScope which is an online logic analyzer. The practice results show the timing mean-square error is less than 1 point which is the same as simulation and the frequency estimation error is less the 1 Hz.

6 Conclusions

In this paper, a fine timing and frequency synchronization algorithm is presented used in CMMB. The presented algorithm could accomplish the timing and frequency offset estimation over AWGN channel and multipath channel. The simulation and practice results show the new algorithm could give out fine timing synchronization within 1 sampling point and accurate frequency offset estimation within 1 Hz over AWGN channel and multipath channel.

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