Research on OFDM Carrier Synchronization

Zhaorui Ma(✉), Zheng Dou, and Zhigang Li

Harbin Engineering University, Nantong Str. 145, Harbin 150001, China
836358835@qq.com

Abstract. OFDM technology is the simultaneous transmission of signals in multiple overlapping channels. In order to correctly receive, the orthogonality of subcarriers must be ensured strictly. However, due to Doppler frequency shift and transceiver of the crystal is not exactly the same, there are certain carrier frequency deviation, which will destroy the orthogonality of the subcarrier wave. The frequency difference influence of phase also has cumulativity, accurate frequency synchronization is the precondition for the normal work of OFDM system. In the text, a typical data-assisted carrier synchronization algorithm is analyzed for the carrier synchronization problem in OFDM system. We studied the improved algorithm which is based on the average algorithm of training symbols, and the performance is compared by simulation analysis. Experiments show that the improved carrier synchronization algorithm is superior to the typical algorithm and has low complexity.

Keywords: OFDM · Frequency deviation · Carrier synchronization
Training symbols · Estimated performance

1 Introduction

There are many researches on the carrier synchronization algorithm at home and abroad. At present, the carrier synchronization algorithm can be divided into two categories according to the data processing [1]: non-data auxiliary class and data assistant class. Non-data-assisted class algorithm is also called blind estimation algorithm. By using the structure of OFDM signal, information is extracted directly from the signal itself (such as cyclic prefix) or after the Fourier transformed spectrum of the signal without using the synchronization parameters from the received signal. And it does not reduce the band utilization, the representative algorithm is based on the cyclic prefix maximum likelihood estimation algorithm [2] (referred to as ML algorithm). The data-assisted method is divided into two parts: the time domain training symbol and the frequency domain training symbol. The concrete realization is that the packet header of the packet is added with an OFDM block dedicated to the frequency offset estimation, such as training symbols or guidance frequency symbols and other additional data information to synchronize the estimation. By changing the pilot or training symbols of the structure, pattern, etc., at the receiving end using related technology to extract synchronization information in the estimation process. This algorithm will reduce the efficiency of system data transmission, and its advantages are fast capture, high precision, suitable for packet data communication.

G. Sun and S. Liu (Eds.): ADHIP 2017, LNICST 219, pp. 425–432, 2018.
https://doi.org/10.1007/978-3-319-73317-3_49

In the text, a typical data-assisted carrier synchronization algorithm is analyzed for the carrier synchronization problem in OFDM system. We studied the improved algorithm which is based on the average algorithm of training symbols, and the performance is compared by simulation analysis.

2 Typical Data Auxiliary Class Algorithm

OFDM system based on IEEE 802.11a is a typical burst packet transmission system. An OFDM symbol is consists of four pilots and 52 subcarriers. The preamble consists of 10 short training sequences and two long training sequences. Therefore, in the system, we generally use the method of data-assisted. We use the long and short training symbols in the preamble to carry out the carrier frequency offset estimation periodically.

2.1 Carrier Frequency Offset Estimation Technique in Frequency-Domain

In the case there are two identical training symbols need to be transmitted consecutively, and the carrier frequency offset is ε, the relationship between the corresponding two received signals is

$$y_2[n] = y_1[n]e^{\frac{j2\pi n\varepsilon}{N}} \leftrightarrow Y_2[k] = Y_1[k]e^{j2\pi\varepsilon} \tag{1}$$

Among them, $y_1[n]$ is the signal of the transmitter, $y_2[n]$ is the signal of the receiver. Using the relationship in (1), we can estimate the carrier frequency offset

$$\hat{\varepsilon} = \frac{1}{2\pi}\arctan\left\{\frac{\sum_{k=0}^{N-1}\mathrm{Im}[\mathrm{Y}_1^*[\mathrm{k}]\mathrm{Y}_2[\mathrm{k}]]}{\sum_{k=0}^{N-1}\mathrm{Re}[\mathrm{Y}_1^*[\mathrm{k}]\mathrm{Y}_2[\mathrm{k}]]}\right\} \tag{2}$$

This is the famous method proposed by Moose [3]. Although the estimated carrier frequency offset range of Eq. (2) is $|\varepsilon| \leq 0.5$, when we use training symbols with D repeating styles, the estimated range of the carrier frequency offset can be increased by D times. If the non-zero samples in the frequency domain which need to be averaged is reduced, the MSE performance will deteriorate. In order to calculate Eq. (2), this estimation technique demands a specific cycle time (often referred to as a leading period) to provide continuous training symbols. In other words, in this estimation technique, the preamble period is applied only to the launch training sequence and can't transmit data symbols.

2.2 Carrier Frequency Offset Estimation Technique in Time-Domain

Compared to the time domain algorithm [4], the frequency domain algorithm needs to calculate the DFT of two repetitive symbols, which requires more computation and consumes more hardware resources and time. So for the WLAN receiver in terms of time domain method has a certain advantage. The time-domain method of frequency offset estimation is the maximum likelihood algorithm for data-assisted operation of the receiving time domain signal [5].

Let the transmission signal be $s(n), f_{tx}$ represents the transmission carrier frequency, T_S represents the sampling period, n corresponds to the sampling point; then after RF modulation, the pass band signal complex baseband model

$$y(n) = s(n)e^{j2\pi f_{tx} nT_S} \tag{3}$$

At the receiving end, f_{rx} represents the carrier frequency, the received signal is converted to baseband signal, in the case of sampling frequency deviation is ignored

$$r(n) = s(n)e^{j2\pi f_{tx} nT_S} \cdot e^{-j2\pi f_{tx} nT_S} = s(n)e^{j2\pi \Delta f nT_S} \tag{4}$$

where the deviation of the carrier between transmitted and received is $\Delta f = f_{tx} - f_{rx}$. Assuming D represents the delay between two consecutive repetition symbols and L represents the OFDM symbol length, the delay correlation of the periodic repetition signal is

$$\begin{aligned} R &= \sum_{n=0}^{L-1} r(\mathrm{i}+\mathrm{n}) r^*(\mathrm{i}+\mathrm{n}+\mathrm{D}) \\ &= \sum_{n=0}^{L-1} s(\mathrm{i}+\mathrm{n}) e^{j2\pi\Delta f(i+n)T_S} \cdot \left[s(\mathrm{i}+\mathrm{n}+\mathrm{D}) e^{j2\pi\Delta f(i+n+D)T_S}\right]^* \\ &= e^{-j2\pi\Delta f D T_S} \sum_{n=0}^{L-1} s(\mathrm{i}+\mathrm{n}) s^*(\mathrm{i}+\mathrm{n}+\mathrm{D}) \end{aligned} \tag{5}$$

When the modulus of the autocorrelation R is the maximum, s(i + n) = s(i + n+D), then

$$Z = R_{s(\mathrm{i}+\mathrm{n}) = s(\mathrm{i}+\mathrm{n}+\mathrm{D})} = e^{-j2\pi\Delta f D T_S} \sum_{n=0}^{L-1} |s|^2 \tag{6}$$

Theoretically, R should be a real number when the frequency offset is 0. The effect of frequency deviation is reflected in $e^{-j2\pi\Delta f D T_S}$. Therefore, the estimated value of the frequency deviation can be calculated as

$$\Delta f = -\frac{\arg(\mathrm{z})}{2\pi D T_S} \tag{7}$$

This algorithm can estimate the carrier frequency offset by two identical OFDM symbols. L and D is the cumulative length and the delay length. These two quantities are based on the situation. If the short training symbol is selected for carrier frequency offset estimation, then L = D = 16; if long training symbol is selected, L = D = 64. Select the different training symbols, the carrier frequency offset estimation effect is different. At the same signal-to-noise ratio, the accuracy of the long and short training sequences is not the same for the carrier frequency estimation, as is shown in Fig. 1.

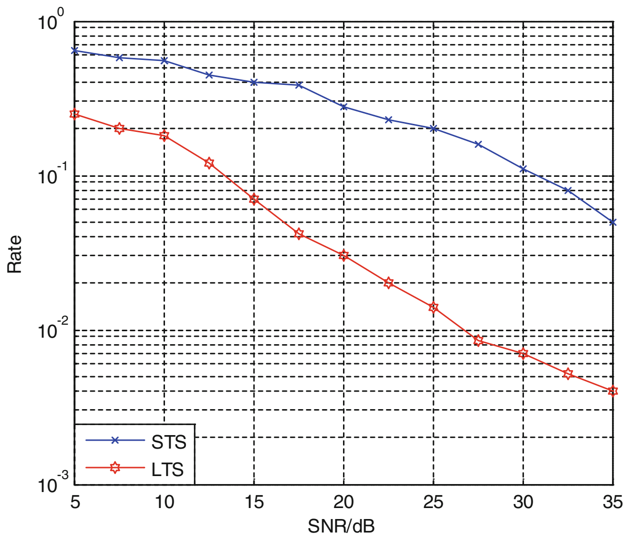

Fig. 1. Carrier frequency offset estimation of time domain algorithm

The Rate represents the percentage of mean square error of estimation of frequency offset among subcarrier spacing. MATLAB simulation of OFDM transmission system to generate the data as the receiving data, set the signal to noise ratio of 5–35 dB, sampling time T_S = 50 ns, adding 10 kHz frequency offset to the system. From the simulation results, it is more accurate to estimate the frequency offset as the SNR increases, but the estimation error of the long training sequence is much smaller than that of the short training sequence.

For IEEE 802.11a systems, the ten short training sequence symbols and two long training sequence symbols in the preamble can be used for carrier frequency estimation [6]. However, for short training symbols, the sampling time is 50 ns, the delay D = 16, the maximum frequency error that can be estimated is

$$f_{\Delta \max} = \frac{\pi}{2\pi D T_S} = \frac{1}{2 D T_S} = \frac{1}{2 \times 16 \times 50 \times 10^{-9}} = 625\ (\text{kHz}) \tag{8}$$

For long training symbols, D = 64, then

$$f_{\Delta\max} = \frac{\pi}{2\pi D T_S} = \frac{1}{2DT_S} = \frac{1}{2 \times 64 \times 50 \times 10^{-9}} = 156.2\ (\text{kHz}) \tag{9}$$

Although the accuracy is high when the long training symbols are used to calculate the frequency offset. However, from the hardware design point of view, the use of long training symbols for frequency offset estimation requires more hardware resources; the most important is the long training symbols can estimate the maximum frequency deviation is too small, only 156.2 kHz. And the short training symbol of the estimated range to 625 kHz, so from the frequency estimation range and the estimated accuracy of the integrated consideration, the use of short training symbols for frequency offset estimation is more reasonable.

3 Estimation Algorithm for Short Training Symbols

Using the repetitive periodicity of short training symbols, the maximum likelihood algorithm is used for carrier synchronization [7, 8]. Assuming that the ideal received signal is $s(n)$, under the influence of the normalized carrier frequency deviation f_Δ, the received signal is

$$r(n) = s(n)e^{j2\pi f_\Delta n T_S} \tag{10}$$

If the short training symbol period is set D^{STS}, the delay correlation variable C_n can be indicated as

$$\begin{aligned} C_n &= \sum_{n=0}^{D^{STS}-1} r(n)r^*(n - D^{STS}) \\ &= \sum_{n=0}^{D^{STS}-1} s(n)e^{j2\pi f_\Delta n T_S}[s(n - D^{STS})e^{j2\pi f_\Delta (n-D^{STS})T_S}]^* \\ &= \sum_{n=0}^{D^{STS}-1} s(n)s^*(n - D^{STS})e^{j2\pi f_\Delta D^{STS} T_S} \\ &= e^{j2\pi f_\Delta D^{STS} T_S} \sum_{n=0}^{D^{STS}-1} s(n)s^*(n - D^{STS}) \end{aligned} \tag{11}$$

According to the maximum likelihood estimation algorithm, the carrier frequency deviation is

$$\hat{f}_\Delta = \frac{1}{2\pi D^{STS} T_S} \arctan[\sum_{n=0}^{D^{STS}-1} s(n)s^*(n - D^{STS})] \tag{12}$$

In order to improve the accuracy of carrier synchronization, the implementation of multiple estimates using the average

$$\hat{f}_{\Delta} = \frac{1}{2\pi D^{STS} T_S} \frac{\sum_{i=0}^{N} \arctan(\sum_{n=0}^{D^{STS}-1} s[(i-1) \times D^{STS} + n] s^{*}[(i-1) \times D^{STS} + n - D^{STS}])}{N} \quad (13)$$

Firstly, five sets of delay correlations are used to calculate the four points of the correlation and the results [9]. Then, the four-time accumulation and the result are estimated by the angular deviation, and then the average of the angular deviation is estimated, so as to get more accurate angle deviation, as shown in Fig. 2.

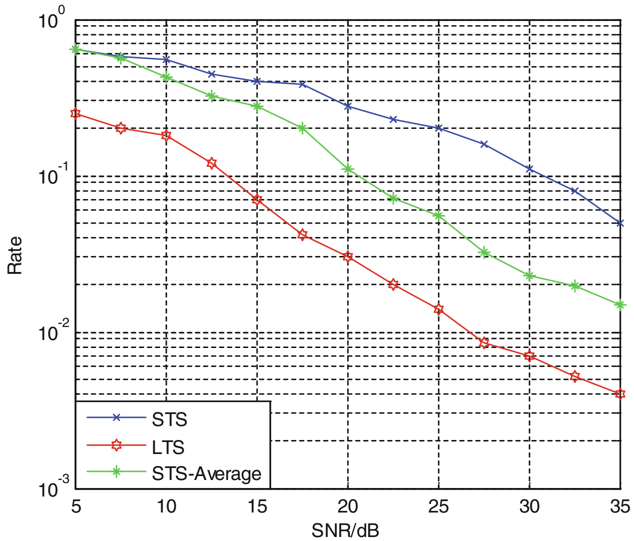

Fig. 2. Comparison of typical algorithm and seeking average algorithm

In the general averaging algorithm, the length of the associated cumulative operation is the length of a short training symbol, so it can only be averaged 9 times in the 802.11a protocol [10]. In order to further improve the accuracy of the frequency offset estimation, from the point of view of averaging, the average of the frequency offset estimates is calculated in the calculation process to obtain more accurate results. Assuming there are M short training symbols, the first two short training symbols are delayed after the correlation operation, with a short training symbol in the sample value, rather than a short training symbol for the unit, the results will be multiplied by the results, constantly related to the cumulative operation.

The delay length is D = 16, and the short training symbol is M. According to the characteristics of the relevant cumulative operation, the following improved algorithm is obtained

$$\overset{\wedge}{\Delta f} = -\frac{1}{2\pi DT_S} \frac{\sum_{i=0}^{(M-2)D-1} \arctan\left(\sum_{i=0}^{D-1} s(n+i) \cdot s(n+i+D)\right)}{(M-2)D} \tag{14}$$

When using 5 short training symbols system carrier synchronization, it can get 48 times the average [11], while ordinary short training symbols for the average algorithm can only seek up to 9 times; In this way, fewer short training symbols can be used to obtain multiple averages, the estimation accuracy of carrier frequency offset will be improved. Under the other conditions remain unchanged, the simulation results of the three algorithms [12], as shown in Fig. 3.

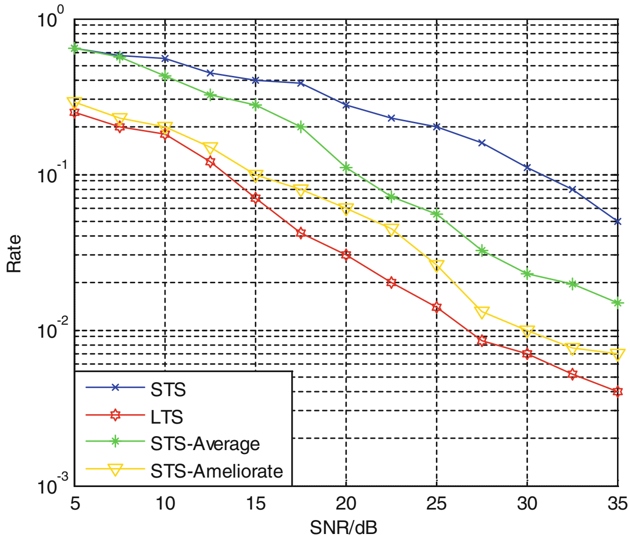

Fig. 3. Comparison between improved algorithm and original algorithm

It can be seen from the above simulation results that the improved averaging algorithm has greatly improved the accuracy of the frequency offset estimation, and it can achieve the ideal effect by estimating the maximum frequency deviation and the estimation accuracy.

4 Conclusion

In this paper, several typical frequency synchronization algorithms are analyzed, and their performance is compared by simulation analysis. Simulation and implementation results show that the error of the improved algorithm is small when compared with the typical algorithm and the averaging algorithm, but the computational complexity is increased. However, compared with the estimation accuracy, the computational complexity increases to a certain extent within the tolerable range, and only the multiplication is used in the hardware implementation. The feasibility of the improved algorithm for frequency offset estimation using short training symbols is verified.

Acknowledgments. This paper is funded by the International Exchange Program of Harbin Engineering University for Innovation Oriented Talents Cultivation, Nation Nature Science Foundation of China (No. 61401115), Nation Nature Science Foundation of China (No. 61301095), Nation Nature Science Foundation of China (No. 61671167).

References

1. Hsieh, M.H., Wei, C.H.: A low-complexity frame synchronization frequency offset compensation scheme for OFDM system over fading channels. IEEE Trans. Veh. Technol. **48**(5), 1596–1609 (1999)
2. Van de Beek, J.J., Sandell, M., Borjesson, P.O.: ML estimation of time and frequency offset in OFDM systems. IEEE Trans. Sig. Process. **45**(7), 1800–1805 (1997)
3. Moose, P.H.: A technique for orthogonal frequency division multiplexing frequency offset correction. IEEE Trans. Commun. **42**(10), 2908–2914 (1994)
4. Zhang, Z.: Research on OFDM synchronization based on maximum likelihood algorithm. Commun. Technol. (2010)
5. Cui, H.: Research on carrier synchronization algorithm in OFDM system. Xi dian University (2015)
6. Xu, J.: Research and implementation of OFDM carrier synchronization algorithm based on 802.11a. University of Electronic Science and Technology of China (2014)
7. Cao, C.: Research on OFDM synchronization algorithm based on IEEE802.11a and FPGA implementation. Inner Mongolia University of Science and Technology (2012)
8. Zhao, D., Yang, Z., Ye, J.: Fast performance simulation of spread spectrum OFDM wideband shortwave communication system. J. Appl. Sci. **36**(10), 8–11 (2009)
9. Cai, X.: Research on OFDM synchronization in burst system. J. Shandong Univ. (Nat. Sci. Ed.) (2016)
10. Cai, L.: Research and implementation of OFDM synchronization technology. J. Xi'an Univ. Electron. Sci. Technol. (2014)
11. Nie, D.: Research on LTE downlink OFDM synchronization. J. Nanjing Univ. Posts Telecommun. (2015)
12. Zheng, J.: Study on synchronization algorithm of broadband wireless OFDM system. Beijing University of Posts and Telecommunications (2008)