Research and Implementation of Cross-correlation Symbol Synchronization Algorithm for Long Training Sequence Based on OFDM System

Guofu Wang1,*, Li Guoyong1, Faquan Zhang2, Jincai Ye1, Xu Guojia 1

1Guilin University of Electronic Technology, Guilin, China
2Wuhan Textile Unviversity, Wuhan, China

*Corresponding Author E-mail: 75516941@qq.com

Abstract. Through the analysis of the classic protocol IEEE 802.11a in OFDM system. An OFDM symbol synchronization algorithm based on Long Training Sequence (LTS) is studied. The symbol synchronization estimation using the LTS sequence symbol cross-correlation method can improve the two parameters of the correlation delay D and the synchronization point decision threshold. It reduces the interference of noise on the decision threshold under the Gaussian White Noise (AGWN) channel and the difficulty of FPGA implementation; improves the accuracy of symbol synchronization and the probability of detecting symbol synchronization under a low signal-to-noise ratio. Simulation experiments and FPGA hardware implementation show that compared with conventional algorithms, the system performance is improved.

1. Preface
Symbol synchronization is the further precision of the data after the frame synchronization is detected. It is a vital part of the OFDM system. In the study of symbol synchronization, Park and Ren et al. Reduced the effect of noise on symbol synchronization by changing the structure and arrangement of periodic cyclic sequences, but the symbol synchronization is still affected in low signal-to-noise ratio and multipath transmission. Decision; in reference [1], the synchronization of multiple-cycle training sequences using a short training sequence (STS) cross-correlation is used to determine the symbol synchronization by judging the number of signal amplitudes at the receiving end exceeding a threshold; By increasing the value of the cross-correlation delay L of the packet detection end to improve the frame detection accuracy and thereby improve the detection probability of symbol synchronization. Based on the IEEE 8021.11 protocol, this paper studies a symbol synchronization technique of the long training sequence symbol (LTS) cross-correlation method. It does not need to change the frame structure. Symbol synchronization greatly improves the probability of detecting symbol synchronization in an OFDM system and improves system performance.1.Symbol synchronization algorithm.
2. Symbol synchronization algorithm

2.1. LTS cross correlation symbol synchronization algorithm

According to the preamble structure designed in the IEEE802.11a protocol, the data output from the receiver carrier synchronization module is cross-correlated with the locally known short training sequence symbols, so as to further accurately estimate the rough estimation of the data packet by the packet detection module to determine the end point of the short training sequence symbol. Multiply and accumulate the received data packet with the conjugate complex number of locally known short training sequence symbols, that is, the correlation coefficient is:

\[ C_k = \sum_{m=0}^{D-1} r_{k+m} \times S_m^* \]  

(1)

Because the short training sequence is limited to four cases: 1 + j, 1-j, -1 + j, and -1-j. Assuming that the local short training symbol is sampled as \( a + jb \), the corresponding operations in the corresponding four cases are:

\[
\begin{align*}
(a + jb) \times (1 + j) &= (a + b) + j(a - b) \\
(a + jb) \times (1 - j) &= (a - b) + j(-a - b) \\
(a + jb) \times (-1 + j) &= (-a + b) + j(a + b) \\
(a + jb) \times (-1 - j) &= (-a - b) + j(-a + b)
\end{align*}
\]

(2)

In formula (1), the superscript * indicates that it is a conjugate. \( D \) is the length of the correlation coefficient, and its size determines the performance of the symbol synchronization algorithm. A larger value can improve performance and reduce the impact of channel noise. Figure 1 shows the simulation results of Matlab in the IEEE 802.11a system with a signal-to-noise ratio of 20dB additive Gaussian White Noise (AWGN) channel. The magnitude of the correlation between the received signal and the local known short training symbol. Get the position of the synchronization symbol according to the frequency and order of the \( |C_k| \) peak, so as to achieve fine synchronization.
2.2. Indirect improvement of STS symbol synchronization algorithm
Taking advantage of the short training period and correlation, as well as the small noise correlation, the received data is auto-correlated with the STS delayed by one period at the receiving end. Due to the strong correlation of the STS, a jump will occur. The specific formula is as follows:

$$C_n = \sum_{k=0}^{L-1} r_{\nu-k-D} r_{\nu-k-D}^*$$

$$P_n = \sum_{k=0}^{L-1} r_{\nu-k-D} r_{\nu-k-D}^* = \sum_{k=0}^{L-1} |r_{\nu-k-D}|^2$$

$$M_n = \frac{|C_n|}{P_n}$$

(3)
T1 and T2 shown in FIG. 2 are two STSs with a length of 16, D is the length of the delay, and L is the length of the delay-related operation. Conventional algorithm L = 16. In this algorithm, L = 32, the length of the delay correlation operation is increased to two STS symbols, and the correlation of noise will become smaller, reducing the impact of noise, improving the accuracy of frame detection and reducing the error of symbol synchronization. As shown in FIG. 3, the indirect improved STS cross-correlation symbol synchronization algorithm and the traditional STS cross-correlation symbol synchronization algorithm have a probability of detecting symbol synchronization at an SNR of 15dB-25dB. When L = 32, the symbol synchronization can be detected 100% when the SNR is greater than 18dB, which is obviously better than the conventional algorithm when L = 16.

![Figure 3](attachment:image.png)

**Figure 3.** Comparison between the improved STS cross-correlation algorithm and the conventional STS cross-correlation calculation under the AGWN channel

### 2.3. LTS cross correlation symbol synchronization algorithm

The closest to the OFDM symbol position is two consecutive long training sequences. Cross-correlation between the locally known long training sequence and the data output from the wave synchronization module is used to further estimate the rough estimation of the packet detection module, that is, the frame synchronization module. The end point of the long training sequence is also determined. The specific method is: firstly group the received data, then multiply and accumulate with the conjugate complex number of the long-known training sequence symbol known locally, and the number of correlations at this time is:

\[
C_j = \sum_{m=0}^{d-1} r_{j-m} \times S_m^* 
\]

In order to simplify the operation of channel estimation, the long training sequence transmitted is limited to three cases: -1, 0, and 1. Let the local long training symbol be sampled as c. The corresponding operation is:

\[
\begin{align*}
  c \times (-1) &= -c \\
  c \times 0 &= 0 \\
  c \times 1 &= c
\end{align*}
\]
According to the PPDU frame structure in the IEEE 802.11a protocol, it can be known that there are two cycles of long training sequence symbols. Each symbol has 64 samples, that is, \( r = 64 \), that is, two peaks will appear. Figure 2 shows IEEE 802.11 Matlab's simulation results of system a in a Gaussian White Noise (AWGN) channel with a signal-to-noise ratio of 20dB.

![Figure 4. LTS cross-correlation symbol synchronization peak diagram](image)

**Figure 4.** LTS cross-correlation symbol synchronization peak diagram

![Figure 5. Principle of LTS symbol synchronization detection](image)

**Figure 5.** Principle of LTS symbol synchronization detection

As shown in Figure 4, the amplitude of the noise is significantly smaller than the peak before the two peaks appear, and the amplitude of the noise is less than 0.2. Figure 5 is the principle structure of the symbol synchronization detection algorithm. In the structure of the LTS in the IEEE802.11a protocol, a peak appears after the correlation calculation of \( d = 64 \). Since the calculated value of the noise correlation is much smaller than the peak value of the LTS correlation, it can be seen from Figure 4 that the two sides of the first peak are obviously not there is interference. Therefore, symbol synchronization can be achieved by detecting the first peak, but for subsequent implementations, it is
convenient to count 16 counts backwards as the symbol synchronization point. The remaining 80 LTS symbols can be removed directly by the counter in subsequent modules. Reduces the use of comparators and the number of additions. The data output by the symbol synchronization is 80LTS symbols, a total of 240 data1 and 80 data2.

3. Comparative analysis of three algorithms
Cross-correlation calculations are performed using 10 STS symbols repeated in consecutive cycles, which consumes a lot of hardware resources. The indirectly improved STS algorithm improves the accuracy of symbol synchronization by improving the accuracy of the frame detection module. It does not reduce the amount of calculations, and the performance improvement is not obvious. However, the LTS symbol cross-correlation = 64 improves the performance of symbol synchronization compared to the short training sequence cross-correlation. The greater the length of the correlation number, the smaller the correlation of noise becomes and the smaller the amplitude value. The smaller the effect on symbol synchronization detection. By comparing formula (2) and formula (5), it can be found that the LTS cross-correlation symbol synchronization method only involves the operation of real numbers and the amount of operation is relatively small. The LTS algorithm can save more hardware resources.

Figure. 6 LTS algorithm performance under AWGN channel
As shown in FIG. 6 and FIG. 7, the change in the probability that the symbol synchronization can be detected and the input signal-to-noise ratio is between 15dB-25dB. It is found that the LTS symbol synchronization algorithm proposed in this paper can detect 100% of the symbol synchronization when the input signal-to-noise ratio is 15dB-25dB. In the STS symbol synchronization algorithm, the symbol synchronization can be detected 100% only when the signal-to-noise ratio is greater than 23dB. Even in the indirect improved STS cross-correlation algorithm, the symbol can be detected 100% after the SNR is greater than 18dB. Synchronized algorithm.

4. FPGA implementation of symbol synchronization based on long training symbol cross correlation method

This design is implemented using the XILINX 7000 chip from XILINX. Figure 8 shows that the synchronization data from MATLAB simulation and the synchronization data from FPGA completely coincide. Figure 9 shows the FPGA demodulated output data and MATLAB simulation using the long training sequence cross correlation method. The demodulated output data is completely consistent with the MATLAB demodulated data, which shows that the method is completely suitable for symbol synchronization in OFDM systems.
Figure 8. Synchronization module data comparison chart

Figure 9. Comparison of the final output data of the demodulation terminal
Figure 9 shows the implementation of the FPGA symbol synchronization algorithm. In this data transmission, there are a total of 560 data, the frame length is 480, there is no Signal field, but it includes noise of 80 data length. Comparing dat_in and dat_out in the red box, it is found that Synch_datou_cnt is finally 240, that is, the data length after synchronization is 240, which is mainly the remaining 80 LTS symbols, 80 data1 and 80 data2. It shows that the algorithm can eliminate certain noise in addition to symbol synchronization. As shown in FIG. 10, it is an enlargement of the blue box in FIG. 9. When CR_max detects the maximum value, syn_cnt continues to count backward 16 clock lengths before it starts to output synchronous data. Consistent with the theory and MATLAB simulation.

5. Conclusion
The LTS cross-correlation symbol synchronization method proposed in this paper is compared with the traditional cross-correlation symbol synchronization method of segment training sequence and its indirect improved algorithm as shown in the following table:

Table 1. Comparison between the improved algorithm and the traditional symbol synchronization algorithm

| Algorithm performance          | Adder Type and Times | Selectable threshold range | Success rate of detected symbol synchronization |
|-------------------------------|----------------------|-----------------------------|-------------------------------------------------|
| LTS cross-correlation method  | Normal adder, 64 times | 0.5-0.8                     | 100%(15dB<SNR<25dB)                             |
| Traditional STS cross-        | Complex adder, 160 times | 0.15-0.2                    | <100%(15dB<SNR<23dB) =100%(>23dB)               |
| correlation method            |                      |                             |                                                 |
| Indirect improved STS         | Complex adder, 160 times | 0.15-0.2                    | <100%(15dB<SNR<18dB) =100%(>18dB)               |
| cross-correlation method      |                      |                             |                                                 |

According to Table 1, compared with the traditional algorithm, the long training sequence cross-correlation method used in this paper occupies less hardware resources, can choose a wider range of
thresholds, has a higher probability of detecting symbol synchronization, and improves the performance of OFDM systems.

Acknowledgement
I would like to thank the teachers in the laboratory for their rigorous academic attitude and noble and peaceful style, which have benefited me a lot. Thanks to the National Natural Science Foundation of China No. 61761009 for funding this project.

References
[1] Faquan Zhang1,2, Guojia Xu1, Jincai Ye1Research on Improved Algorithm of Frame Detection for COFDM High-Definition Wireless Transmission System and FPGA Implementation[J]. Energy Science and Power Engineering,2019
[2] Liu Mengyang, Wang Hongjuan, Li Yeli. Design of Joint Synchronization Algorithm for OFDM Based on Cyclic Prefix [J]. Journal of Beijing Institute of Graphic Communication
[3] Hai Ling. Frequency synchronization algorithm based on time domain oversampling in OFDM system [J]. Software Engineering, 2019,22 (08): 4-6
[4] Chen Ying, Nie Wei. Improved training sequence structure and time-frequency synchronization algorithm for OFDM system [J]. Application of Electronic Technique, 2019,45 (06): 89-92 + 96.
[5] Hu Zhengwei, He Dongmei, Xie Zhiyuan. The timing synchronization algorithm of OFDM symbols for power line communication [J]. Electric Power Automation Equipment, 2019,39 (05): 144-150.
[6] For the Grid and Through the Grid: The Role of Power Line Communications in the Smart Grid. Galli, S., Scaglione, A., Zhifang Wang. Proceedings of Tricomm. 2011
[7] Di Chang, Xia Zhang, Qiong Liu, Ge Gao, and Yue Wu. "Location based robust audio watermarking algorithm for social TV system." In Pacific-Rim Conference on Multimedia, pp. 726-738. Springer, Berlin, Heidelberg, 2012.
[8] Di Chang, Xia Zhang, and Yue Wu. "A Multi-Source Steganography for Stereo Audio." Journal of Wuhan University (Natural Science Edition), 2013(3): 277-284.
[9] Xia Zhang, Di Chang, Weimin Qi, and Zhiming Zhan. "Tree-like Dimensionality Reduction for Cancer-informatics." In IOP Conference Series: Materials Science and Engineering, vol. 490, no. 4, pp. 042028. IOP Publishing, 2019.
[10] Liang Ding, Di Chang, et al. "Efficient Learning of Optimal Markov Network Topology with k-Tree Modeling." arXiv preprint arXiv:1801.06900 (2018).
[11] Xia Zhang, Di Chang, et al. "An audio digital watermarking algorithm transmitted via air channel in double DCT domain." In 2011 International Conference on Multimedia Technology, pp. 2926-2930. IEEE, 2011.
[12] Wu Xueqi, Liu Jianfei, Zeng Xiangyi, Lu Jia, Xu Yaping. A Timing Synchronization Algorithm for CO-OFDM System Based on PN Sequence [J / OL] . Acta Optica Sinica: 1-11 [2019-12-01].