Research on Improved Algorithm of Frame Detection for COFDM High-Definition Wireless Transmission System and FPGA Implementation

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Abstract. COFDM is one of the more advanced modulation technologies. COFDM wireless image transmission technology is adopted on high-speed mobile UAVs, which can meet the requirements of long-range aerial photography and monitoring. Frame detection is the first step in receiving data. The accuracy of the detection data directly affects the reliability and robustness of the reception performance. Through the research of traditional energy detection algorithm, a delay correlation algorithm based on 802.11a frame structure is adopted, which overcomes the shortcomings of large energy variation and rapid decrease of threshold under low SNR. It also achieves good frame detection performance and can be implemented on an FPGA. Combined with the simulation results of ISE, the frame detection algorithm is suitable for COFDM high-definition wireless image transmission system.

1. Introduction
COFDM high-definition wireless image transmission system adopts multi-carrier transmission technology, which has the advantages of “non-line-of-sight” and “diffractive” transmission. It can be realized in an environment with densely populated cities, mountains, buildings and inside and outside obstacles. Consistent quality image transmission, independent of the environment. In a complex electromagnetic interference environment, COFDM has strong anti-channel fading capability through joint coding of each subcarrier. In order to enable COFDM to correctly demodulate data, an efficient synchronization mechanism needs to be introduced. The role of frame detection is to detect the arrival of data frames. The performance of the frame will directly affect the accuracy of subsequent synchronization, which in turn affects the reliability of the entire system.

2. COFDM frame detection algorithm
2.1. Energy Detection Algorithm
Measuring the energy of the received signal is one of the simplest detection algorithms. When no data packet arrives, there is only noise in the received signal \( r_n \), that is, \( r_n = w_n \); when the packet data arrives, the component of the signal is added to the received signal, that is, \( r_n = s_n + w_n \). Therefore, the energy of the received signal can be detected in packets. In order to avoid the influence of sudden large noise,
the decision variable $m_n$ is selected as the cumulative sum of the received signal energy under the window L, which can be expressed as:

$$m_n = \sum_{k=0}^{L-1} r_{n-k}^* r_{n-k} = \sum_{k=0}^{L-1} |r_{n-k}|^2$$  \hspace{1cm} (1)

As can be seen from equation (1), $m_n$ is the summation of the received signal motion, also known as the sliding window. The principle is that at any time n, the summation will add a new value and discard an old value. Figure (1) shows the change of the decision variable $m_n$ in the sliding window L=32 when the IEE802.11a data packet has a signal-to-noise ratio of 15 dB under the AWGN channel. It can be seen from the Matlab simulation that there is a period of noise at the beginning. When n=290, the received energy jumps and rises rapidly to about 4.5. Although the method is simple, the judgment threshold needs to be determined by the received energy, and the noise power value in the received signal is generally unknown, so it is difficult to determine the threshold point.

![Figure 1](image1.png)

**Figure 1.** Received energy signal detection

![Figure 2](image2.png)

**Figure 2.** Double sliding window grouping detection

### 2.2. Double sliding window grouping detection algorithm

The double sliding window grouping detection algorithm, the basic principle is to obtain the decision variable $m_n$ by calculating the ratio of the energy of two consecutive windows. The schematic diagram of the two windows is shown in Figure 3:
When the data window $A$ is grouped, the energy of the window $A$ gradually increases, and the energy of the window $B$ does not change. When the packet data arrives between $AB$, the energy of window $A$ reaches its maximum. When the data passes through the window $A$ and reaches the window $B$, the energy of the window $B$ gradually increases, and the energy of the window $A$ gradually decreases. The two window energy calculation formulas are as follows:

$$a_n = \sum_{m=0}^{M-1} r_{n-m} r_{n-m}^* = \sum_{m=0}^{M-1} |r_{n-m}|^2$$  \hspace{1cm} (2)$$

$$b_n = \sum_{i=0}^{L} r_{n+i} r_{n+i}^* = \sum_{i=0}^{L} |r_{n+i}|^2$$  \hspace{1cm} (3)$$

In equations (2) and (3), $M$ and $L$ represent the lengths of window $A$ and window $B$, respectively, and $a_n$, $b_n$ represent the energy values of the two sliding windows, dividing $a_n$ and $b_n$ to obtain the decision variable $m_n$:

$$m_n = \frac{a_n}{b_n}$$  \hspace{1cm} (4)$$

Figure 2 shows the change of $m_n$ using the double-sliding window detection algorithm when the IEEE802.11a data packet has a signal-to-noise ratio of 15 dB under the AWGN channel and the sliding window length is $L=32$. It can be seen from the Matlab simulation that the value of $m_n$ is independent of the total received power; although the received energy after the peak increases, it will return to the level before the peak. When the data packet just enters window $A$, the value of $m_n$ is below 4, and after fully filling two windows, the value of $m_n$ is also below 4. Through the peak to determine the arrival of valid data, the ratio of the two energies, although narrowing the selection range of the threshold, but the energy change is uncertain, the selection of the threshold becomes difficult.

Both of the above algorithms use the method of calculating energy to select the threshold, but the change of the received energy is fluctuating, which makes the threshold selection difficult to determine, which is not conducive to engineering implementation.

2.3. Improved delay correlation detection algorithm based on IEEE802.11a preamble structure

As shown in Fig. 4, the IEEE802.11a preamble structure is composed of 10 short training sequences of length 16 and two long training sequences of length 64 and 32 cyclic prefixes.

![Figure 4. IEEE 802.11a preamble structure](image)

**Figure 4.** IEEE 802.11a preamble structure

![Figure 5. Schematic diagram of an improved delay correlation detection algorithm](image)

**Figure 5.** Schematic diagram of an improved delay correlation detection algorithm
The preamble structure implements a very simple and effective packet detection algorithm for the receiver. The algorithm improves the previous two energy-based algorithms by using the periodicity and correlation of the short-term training symbols in the preamble and the low noise correlation. An improved delay correlation detection algorithm based on the preamble structure is formed. The algorithm delays the period of a short training sequence and receives the autocorrelation operation after receiving the signal at the receiving end. Since the short training sequence is repeated for 10 consecutive cycles, and the selected short training sequence has a strong autocorrelation, the autocorrelation operation value is close to its energy value. The noise is not correlated, and the value obtained after correlation is small, so a jump occurs between the noise and the short training sequence. The relevant formula is as follows:

\[ C_n = \sum_{k=0}^{L-1} r_{n-k}^* r_{n-k-D} \]  
\[ P_n = \sum_{k=0}^{L-1} r_{n-k-D} r_{n-k-D}^* = \sum_{k=0}^{L-1} |r_{n-k-D}|^2 \]
\[ m_n = \frac{|C_n|}{P_n} = \frac{\sum_{k=0}^{L-1} r_{n-k-D} r_{n-k-D}^*}{\sum_{k=0}^{L-1} |r_{n-k-D}|^2} \]  

As shown in Fig.5 is a simplified schematic diagram of an improved algorithm for delay correlation detection based on the IEE802.11a preamble structure. T1 and T2 are two short training sequences of length 16, D represents the length of the delay, and L is the length of the delay correlation operation.

Comparing the decision value \( m_n \) with the threshold \( K \), when \( m_n > K \), it indicates that the data packet has arrived, otherwise the reverse. Figure (6) (7) shows that the 802.11a data packet is in the AWGN channel, the signal-to-noise ratio is set to 20dB, and when \( D=16 \), \( L=16 \) and \( L=32 \), when the delay correlation algorithm is used for packet detection, the decision is made. The change in the value \( m_n \). When \( L=32 \), it can be seen that when two short training sequences are used for correlation, the correlation value of noise is smaller, and the fluctuation of \( m_n \) near 1 is smaller, which is more favorable for the selection of threshold \( K \). It can also be seen that when \( L=32 \), the \( m_n \) values outside the short training sequence are basically below 0.4, which is beneficial for the FPGA to select the threshold.

When the threshold is 0.75, in different SNR environments, when \( L \) is 16 and 32 respectively, the probability of correct group detection is shown in Figure 8. It can be seen from Fig. 8 that when the signal-to-noise ratio (SNR) is below 25 dB, the correct packet detection probability of \( L=32 \) is higher than the correct packet detection probability of \( L=16 \). Therefore, when \( L=32 \) is selected, the accuracy of frame detection is higher, which is beneficial to symbol synchronization to accurately determine the starting position of a symbol, thereby improving the performance of the entire system.

![Figure 6. L=16 delay-related packet detection algorithm](image-url)
Figure 7. L=32 delay-related packet detection algorithm

Figure 8. Performance comparison of packet detection algorithms under AWGN channel

3. Frame detection hardware structure and simulation

This design uses the zynq7000 chip implementation of XILINX, and uses the simulation software that comes with ISE. As shown in Figure 9, where bitInR and bitInI are the real and imaginary parts of the current data, bitOutR and bitOutI are the real and imaginary parts of the current data output, FrameEnable is the frame valid enable signal, and SumDelayCorrection is the delay related energy summation. The value of Sum16Magnitude represents the summation of the packet data energy. The received data is generated by the IEEE 802.11a OFDM transmission system simulated by MATLAB, which is converted into two's complement code as the data source for the receiver detection. The packet data has a total of 960 data, of which the first 480 are noise data, and the last 480 are valid data frames. The threshold is chosen to be 0.5 for FPGA implementation. It can be seen that after the reset, the input data frame lasts for a total of 19.2us, and the output data frame continues for 9.8us, indicating that the improved frame detection algorithm causes some of the noise data to be filtered out.

As can be seen from Figure 10, when the FrameEnable signal is pulled high, it indicates that the valid data frame arrives, and the valid data frame is directly output. At this point, it can be seen that the SumDelayCorrection signal is converted to an unsigned decimal number of 848, and the Sum16Magnitude signal is also converted to none. The number of symbols is 921, and the ratio of the two is close to 1, which is consistent with the theoretical simulation results.
From the simulation results, the improved delay-correlation detection algorithm based on the IEE802.11a preamble structure has a certain delay, but the detection accuracy is greatly improved, the threshold range is small, easy to select, and can be implemented in hardware.

4. Conclusion

The first module of the COFDM high-definition wireless picture transmission system receiver is also an important module. The accuracy of the detection directly affects the accuracy of the subsequent synchronization, which affects the stability of the whole system. The improved preamble structure proposed in this paper performs delay correlation detection algorithm. Compared with other energy algorithms, the precision is higher, the threshold is easier to select, and less FPGA hardware resources are needed, which can save hardware resources.

Acknowledgments

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