Synchronization Design of Frequency-Hopping Communication System

Zhao Xiangwu，Quan Houde，Cui Peizhang
Department of Information Engineering
Army Engineering University Of P.L.A. Shijiazhuang,China
Email:zhaoxiangwu1201@163.com

***Abstract*—Frequency hopping is one of the most classic examples of spread-spectrum communications. This paper is about the study of the strategy of the synchronous process. Modern frequency hopping systems generally use the sliding correlation scheme and the matched filter scheme which have the best anti-jamming performance. However, the sliding correlation scheme converges too slowly while the matched filter scheme occupies too much hardware. An improved acquisition scheme is developed which reduces the acquisition time, has excellent anti-jamming ability and limits the system complexity. The improved scheme not only keeps the best anti-jamming performance and an acquisition speed almost as fast as the classical matched filter scheme acquisition,but also has a simple structure which is comparable to the classical sliding correlation acquisition.**

***Keywords*:spread-spectrum communications,frequency-hopping synchronization,anti-jamming, acquisition time.**

I. Introduction

Frequency hopping communication is the main measure of the battle-field communication. One of the key technologies is frequency hopping synchronization which affects the performance of frequency hopping communication system directly.Synchronization design of frequency hop-ping communication system has been the focus of this paper.

The prerequisite of frequency hopping communication receiving frequency hopping signals correctly is that both the transmitter and the receiver must complete synchronization.Generally speaking, the receiver and transmitter use the same frequency at the same time.Frequency hopping synchronization is completed by synchronization acquisition and synchronization tracking. Synchronization acquisition completes the rough synchronization on 1/2 frequency gapping width; the further precise synchronization is completed by synchronization tracking.The performance of the whole synchronization system is determined by the performance of synchronization acquisition largely.Since the occurrence of frequency hopping communication technology in 1950s,the synchronization system has been studied widely[1].

According to the difference of receiving the synchronization information， the methods of frequency hopping synchronization can be divided into the independent channel method, the pre-synchronization method and the self-synchronization method. The self-synchronization method has been paid much attention because it does not require additional synchronization information in comparison to other methods. There are mainly methods base on the self-synchronization method, such as the matched filter scheme, the sliding correlation scheme, the waiting search scheme, and the fast scanning scheme[2].The anti-interference performance of the matched filtering scheme and the sliding correlation scheme is better than the fast scanning scheme[2-6].The waiting search scheme has the worst anti-jamming performance [7].

This paper analyzes and compare the performance of the matched filter scheme and the sliding correlation scheme.based on the theoretic reaearch, this paper put forward a scheme of design of frequency hopping synchronization system.The algorithm has been implemented and the performance of anti-interference has been improved.

II. Traditional Frequency Hopping Synchronization Method

A. Schematic Diagram

The work flow of traditional frequency hopping radio usually includes initial synchronization and normal communication.The initial synchronization consists of three

978-1-5386-1803-5/18/$31.00 ©2018 IEEE

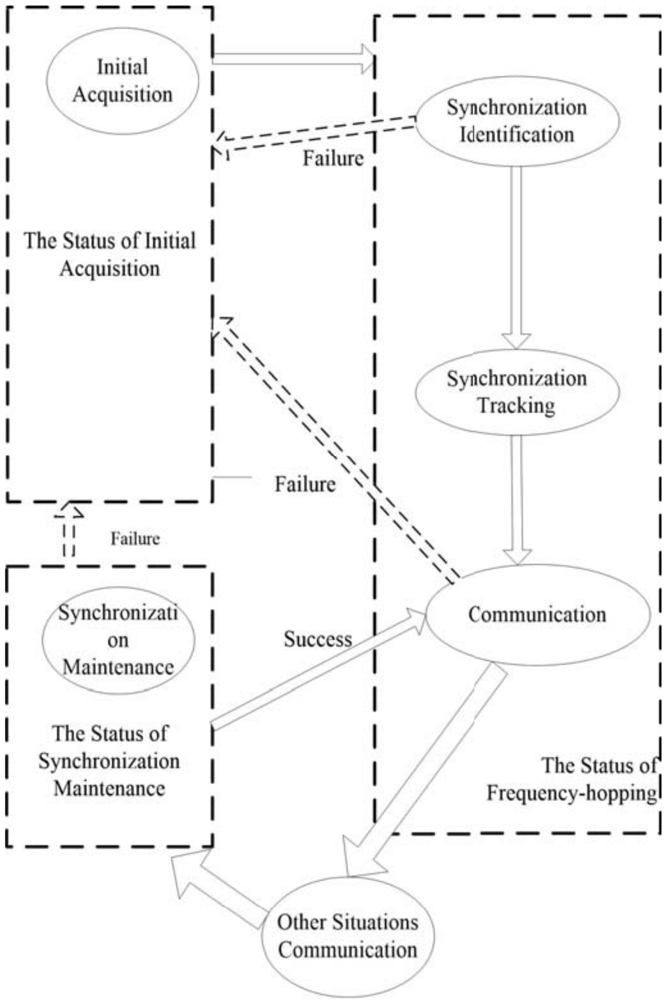

Fig.1. Diagram of the relation between work flow and work status of the self-synchronization scheme

stages: Initial acquisition stage , synchronization identification stage and synchronization tracking stage.The working status of the frequency hopping receiver are the initial acquisition state, the frequency hopping state and the synchronization maintenance state.In the process of initial synchronization, synchronization information is transmitted through the frequency hopping synchronization guidance code that helps the transmitter and receiver complete the initial synchronization.In the normal communication process, the direct digital synthesizer(DDS) of the receiver operates in the state of frequency hopping ,and it generates the local signal of frequency hopping . The transformation relation of work flow and work status is shown in Fig1[8,9].The real arrow in the graph indicates the positive direction of the process, and the dashed arrow indicates the amended direction.

B. The Sliding Correlation Scheme

The frequency output of the local dds has exactly the same rule of the frequency jump of the transmitter. Then the frequency is mixed. According to the output of the envelope detector ,we can judge the frequency hopping point of the transmitter and receiver, the same as "1"and the difference is "0".Finally, the judgement results of a frequency hopping cycle are added ,and the search instructions are controlled according to the judgement results. If the output of the counter exceeds a predetermined threshold value, it is considered that the acquisition process is successful and frequency hopping communication enters the tracking state. If the output of the counter is lower than the threshold value, the frequency jump rule of the local frequency synthesizer is different from the sender. The local frequency hopping sequence is phased through the search instruction, which usually phase shift 1/2 frequency gapping until the acquisition is successful,as shown in Fig.2.

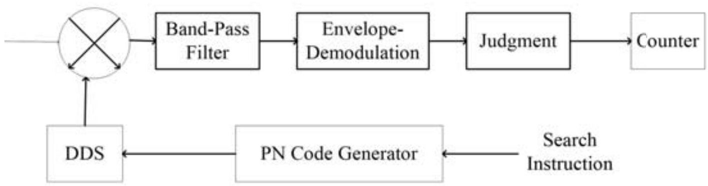

Fig.2.the schematic diagram of the sliding correlation scheme

C. The Matched Filter Scheme

The length of frequency hopping sequence cycle is L, so there are L band- pass filters corresponding to each hopping frequency point of frequency hopping system. The center frequency of the band-pass filters is controlled by the local search controller. The output signal of the matched filters is delayed and the cumulative result is judged. If each center frequency of matched filters in the L frequency gappings is corresponding to the frequency of the transmitter.The predetermined threshold value will be exceeded by the accumulated value.The synchronization acquisition is successful, otherwise continuing to control the center frequency of each matched filter until the acquisition is completed.The schematic diagram is shown in Fig. 3.

D. Performance Comparison

In terms of the complexity of system structure, the matched filter scheme requires L tributary units.However, the

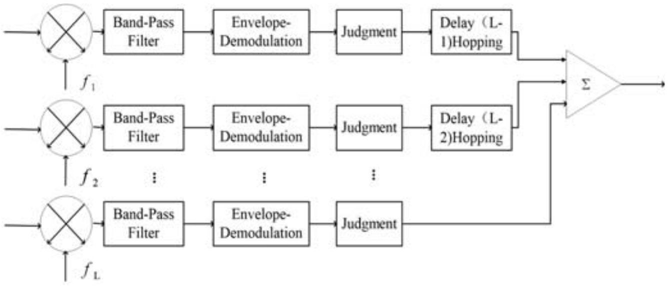

Fig.3.the schematic diagram of the matched filter scheme

sliding correlation scheme requires only one tributary unit. The system structure of the sliding correlation scheme is simple,and the scheme is widely used.

All the accumulated results of the correlation demodulation on a frequency hopping period are judged.If the same cycle length of frequency hopping sequence and the same threshold value are used,the performance of anti-interference is exactly identical.

Definition 1. The probability of synchronization acquisition in the k frequency gapping by the matched filter scheme is:

$$\rho_{(\mathrm{k})} = \begin{cases} 0, & 0 \le k \le L; \\ 1/L, & L \le k \le 2L. \end{cases} \tag{1}$$

Where L is the cycle length of the frequency hopping sequence.

The expectation of acquisition time is:

$$\begin{aligned} \Gamma &= \sum_{k=0}^{2L-1} \{\rho_{(\mathrm{k})} k T_0\} \\ &= \sum_{k=L}^{2L-1} \frac{1}{L} k T_0 = \frac{3L-1}{2} T_0. \end{aligned} \tag{2}$$

Where T_0 is the frequency gapping of frequency hopping.

Definition 2. The probability of synchronization acquisition in the k frequency gapping by the sliding correlation scheme is:

$$\rho_{(\mathrm{k})} = \begin{cases} 1/L, & k = \mathrm{nL}, \mathrm{n} = 1,2,\bullet\bullet\bullet,\mathrm{L}; \\ 0, & \text{else}. \end{cases} \tag{3}$$

The expectation of acquisition time is:

$$\begin{aligned} \Gamma &= \sum_{n=0}^{L} \{\rho_{(\mathrm{nL})} nLT_0\} \\ &= \sum_{n=1}^{L} \frac{1}{L} nLT_0 = \frac{L^2+L}{2} T_0. \end{aligned} \tag{4}$$

From the calculation results of the expectation of acquisition time, the matched filter scheme is O(L) while the sliding correlation scheme is O(L^2) .This means that the matched filtering method is much better.

III. THE IMPROVED SCHEME AND PERFORMANCE ANALYSIS

A. The Improved Scheme

Based on the correlation results， the algorithm of the improved scheme makes an outgoing judgement in the P frequency gapping.If the judgment standard shows that synchronization is unsuccessful, the current frequency hopping sequence will be slid out fast.The correlation and judgment of local frequency hopping sequence and the received signal will be restarted until we can achieve acquisition.The schematic diagram is shown in Fig.4.

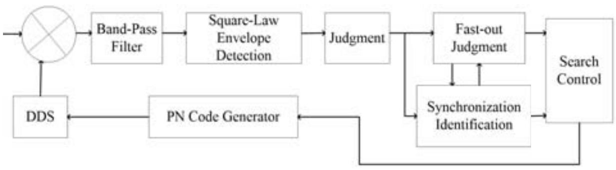

Fig.4.the schematic diagram of the improved scheme

B. Performance Analysis

Figure 4 shows that the system structure of the fast outgoing scheme is much better than the structure of the matched filter scheme.In addition to the complexity of search control center is increased,only one outgoing judgement unit is added to the search control center compared with the sliding correlation scheme.

Definition 3. The probability of synchronization acquisition in the k frequency gapping by the improved scheme is:

$$\rho_{(\mathrm{k})} = \begin{cases} 1/L, & \mathrm{k} = \mathrm{L} + \mathrm{nP}, \mathrm{n} = 0,1,2,\bullet\bullet\bullet,\mathrm{L}-1; \\ 0, & \text{else}. \end{cases} \tag{5}$$

Where P is the parameter of the outgoing judgement.

The expectation of acquisition time is:

$$\Gamma = \sum_{k=0}^{+\infty} \{\rho_{(k)} k T_0\}$$
$$= \sum_{k=L}^{+\infty} \frac{1}{L}(L + n\mathrm{P})\ T_0 = LT_0 + \frac{L-1}{2}\mathrm{P}T_0. \tag{6}$$

It is shown in formula (6) that the acquisition time expectation of the improved algorithm is far less than the sliding correlation scheme without interference.When P=1 ,the expectation value of the improved algorithm is equal to the expectation value of the matched filter scheme, which achieves the minimum expectation value of the acquisition time.

The main performance of the anti-jamming are the false acquisition probability and the missing acquisition probability. Compared with the sliding correlation scheme ,the fast outgoing acquisition scheme does not increase the false acquisition probability, so we only need to study the miss acquisition probability.for single- frequency interference,the improved scheme is studied.

The amplitude of the target signal is $\mathrm{A_s}$ .The amplitude of the interference signal is $\mathrm{A_i}$ .The phase angle between $\mathrm{A_s}$ and $\mathrm{A_i}$ is θ ,and $\theta \subset [0, 2\pi]$.

Definition 4. The synthetic signal amplitude of $\mathrm{A_s}$ and $\mathrm{A_i}$ is:

$$A_v = \sqrt{\mathrm{A_S^2} + \mathrm{A_i^2} - 2\mathrm{A_s}\mathrm{A_i}\cos\theta}\,. \tag{7}$$

If there is a missing acquisition probability,we can get:

$$\cos\theta > \frac{\mathrm{A_S^2} + \mathrm{A_i^2} - A^2}{2\mathrm{A_s}\mathrm{A_i}}. \tag{8}$$

If the probability of appearing interference at each frequency gapping is α **,** the missing acquisition probability of each frequency gapping is shown in formula (9):

$$P_l = \frac{\alpha}{\pi}\arccos\frac{\mathrm{A_S^2} + \mathrm{A_i^2} - A^2}{2\mathrm{A_s}\mathrm{A_i}}. \tag{9}$$

If more than Q frequency gappings are missed in a frequency hopping cycle,the probability of system missing acquisition is:

$$P_s = \sum_{j=Q}^{\mathrm{L}} C_L^j P_l^j (1-P_l)^{L-j}, \tag{10}$$

Where C_L^j is combinatorial number.

Compared with the classical sliding correlation scheme, the acquisition of fast outgoing sliding scheme may be missed by the outgoing judgement.So the scheme introduces increment of the missing acquisition probability. In order to facilitate analysis, the range of P is limited to [Q/2, Q].

If the frequency gappings of continuous missing acquisition have only P, the probability which the total missing acquisition numbers is less than Q is :

$$P_{\mathrm{P}} = \sum_{j=P}^{Q-1} C_L^1 C_{\mathrm{L\text{-}P\text{-}2}}^{j-\mathrm{P}} P_l (1-P_l)^{L-j}. \tag{11}$$

If the frequency gappings of continuous missing acquisition have only P+1, the probability which the total missing acquisition numbers is less than Q is :

$$P_{\mathrm{P+1}} = \sum_{j=P+1}^{Q-1} C_L^1 C_{\mathrm{L\text{-}P\text{-}3}}^{j-P\text{-}1} P_l^j (1-P_l)^{L-j}. \tag{12}$$

Compared with the classical sliding correlation scheme,the increment of the miss acquisition probability of the improved scheme is:

$$\Delta P = \sum_{i=P}^{Q-1} \mu_i P_i$$
$$= \sum_{i=P}^{Q-1}\left[\frac{i-P+1}{L}\sum_{j=i}^{Q-1} C_L^1 C_{L-i-2}^{j-i} P_l^j (1-P_l)^{L-j}\right] \tag{13}$$

IV. EMULATION ANALYSIS

A. The Contrast of Performance Between Improved Scheme and Classical Scheme

In order to obtain the comparison curves of the acquisition time expectation value of three schemes, the paper conduct the emulation without interference.The parameters are set as follows:P=0.3l,L $\subset$ [1,512].The simulation result is shown in Fig.5.

From the comparison curves in figure 5, we can realize that the fast outgoing sliding scheme saves a large number of acquisition time compared with the classical sliding correlation method. When P=0.3L, the expectation of acquisition time is about 15% of the classical sliding scheme expectation value .

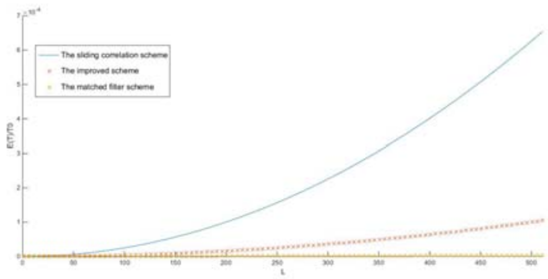

Fig.5.the comparison curves of the acquisition time expectation value

B. *The Effect of Parameter P on Acquisition Performance*

When L=256, α =0.40, P_l =0.10,while $Q = L \times (\alpha + P_l)/2$, we plot the function relation dragram of P and ΔP ,as shown in the following Fig.6.

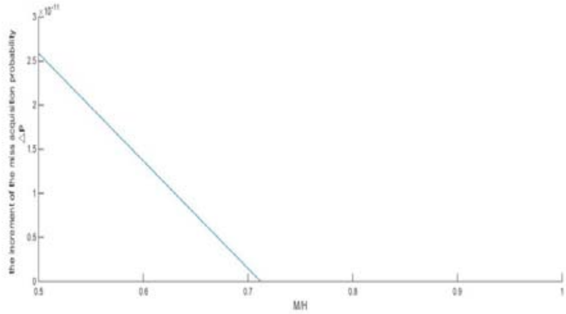

Fig.6.the function relation dragram of P and the increment of the miss acquisition probability

Figure 6 shows that the increment of the miss acquisition probability is about 10^{-11} order of magnitude.When P/Q>0.72 ,the increment of the miss acquisition probability will be close to zero.The choice of parameter P has a comprehensive consideration form the expectation value of acquisition time and the performance of anti-interference.

Even in strong interference , for example,the 30 percent frequency is interfered and the probability of the missing acquisition is 10 percent, and P=0.7Q.The improved scheme can also save plenty of acquisition time.After many simulation experiments,when P=0.7Q,the improved scheme can ensure the communication system which has better anti-interference performance and acquisition time.

V. CONCLUSIONS

This paper analyzes and compares the performance of the matched filter scheme and the sliding correlation scheme,and the synchronization acquisition schemes have reliable anti-jamming performance.Based on the comprehensive requirements of three indexes, such as strong anti-interference, short acquisition time and simple system structure, an improved acquisition scheme is proposed. This scheme is improved form the sliding correlation scheme. The improved scheme not only keeps the best anti-jamming performance and an acquisition speed almost as fast as the classical matched filter scheme acquisition,but also has a simple structure which is comparable to the classical sliding correlation acquisition.And then ,this pass takes a soft simulation and verifies about the design of the acquisition using MATLAB. The future research work is that how to improve system performance with tracking interference.

REFERENCES

[1] MEI Wenhua. Frequency Hopping Communications [M].Beijing: Publishing House of National Defence Industry.

[2] WANG Dan, HUANG Ruiguang. Analysis and research on synchronization system for slowly frequency-hopped in short-wave [J].Telecom Express, 2002,11: 23-26.

[3] Sheen W H, Tseng C C, Wang H C. Multiple-dwell and sequential code acquisition with diversity for FFH/MFSK spread-spectrum systems under band multitone jamming [J].IEEE Transactions on Communications, 2000,48(5):841-851.

[4] Jovanovic V M. Acquisition of frequency-hopping spread spectrum signals by sequential detection [J].Military Communications Conference, 1989,3: 870-874.

[5] Miller L E, Lee J S, French R H, et al. Analysis of an anti-jam FH acquisition scheme [J].IEEE Transactions on Communications, 1992,40(1): 160-170.

[6] Chung Chardir, Huang Pingchia. Performance analysis of a fast FH/BFSK acquisition receiver in non selective fading channels [J].Military Communications Conference, 1994,2: 400-404.

[7] Fujino S, Oie T, Iritani T. A study of performance of frequency

hopping-spread spectrum communication using rapidly synchronous acquisition system [J].Singapore:ICCS/ISITA, 1992,2: 745-749.

[8] Putman C, Rappaport S, Schilling D. A comparison of schemes for coarse acquisition of frequency-hopped spread-spectrum signals [J].IEEE Transactions on Communications, 1983,31: 183-189.

[9] Harri Saarnisaari Henri Puska. Matched Filter Time and Frequency Synchronization Method for OFDM Sytems using PN-sequence Preambles[C]. 2007 IEEE 18th International Symposium on Personal,Indoor and Mobile Radio Communications，2007:1-4.