A New Acquisition Method in FFH System

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***Abstract*—Modern Fast Frequency Hopping (FFH) systems generally use the sliding correlation scheme and the matched filter scheme which both have the best anti-jamming performance. However, the sliding correlation scheme converges too slowly and the matched filter scheme occupies too much hardware resource. An improved acquisition method was developed. Compared with the former two methods, the new method which has the same synchronization probability and false alarm probability, decreases the mean acquisition time and reduces the hardware complexity. Simulations show that, the improved scheme which keeps the best anti-jamming performance, has a simpler structure than the classical sliding correlation acquisition. Meanwhile, the acquisition speed of the new method is almost as fast as the classical matched filter acquisition.**

Keywords-FFH system; synchronization acquisition; mean acquisition time

I. INTRODUCTION

Frequency Hopping (FH) technique is widely used in civil and military for its excellent properties such as the anti-jamming ,anti-fading and anti-interception[1][2][3]. Existing FH techniques is classified into two basic categories, one is Slow FH (SFH) which transmits information stream at a symbol rate higher R_s than its hopping rate R_h, or send more than 1 symbol on a single carrier frequency; The other is Fast FH (FFH), which by its definition has $R_h > R_s$, or switch its carrier frequency multiple times in the transmission of 1 symbol. Obviously, FFH is more robustness in the presence of frequency-selective fading effect and narrow-band interferences than the traditional SFH systems. But high-speed frequency hopping rate brings about a series of problems [4][5], of which the synchronization acquisition is the most challenging issue. The fundamental problem in this area is to effectively acquire coarse time alignment between the received signal tone and the receiver's local dispreading tone with 1/2 code-hop interval.

The existing traditional synchronization acquisition methods can be classified into two basic types, slippage correlation acquisition (serial synchronous method) and matched filtering acquisition (parallel synchronous method)[6]. However, the capture time of the serial synchronous method is long and the parallel synchronous method have a complex receiver structure. For decreasing the complexity of the receiver structure and reducing the capture time, this paper proposes a new synchronization acquisition method which maintains the performance of the detection probability and false alarm probability.

This paper is organized as follows. Section II describes the FFH system acquisition models. And the proposed new algorithm is discussed. The per-formance is analysed in Section III. Section IV presents simulation results. Finally, Section V concludes this paper.

II. SYSTEM MODEL

A. Classical Acquisition Methods

1) Slippage correlation synchronization acquisition: As shown in Fig.1, there is only one receiving mixer. In slippage correlation synchronization acquisition (SCSA), receiver's frequency synthesizer is controlled to emit at a random frequency hopping sequence code phase and then generate a frequency hopping sequence waiting for corresponding signals. The capture time of the slippage correlation acquisition will be one hop duration.

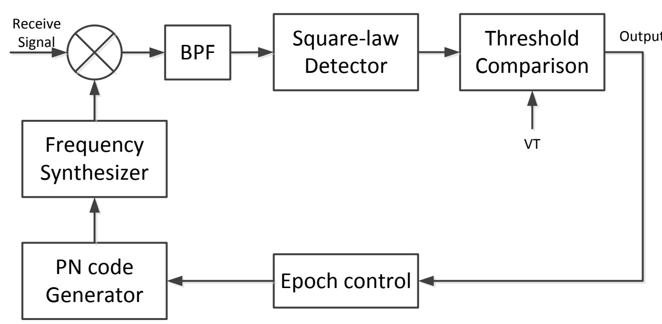

Fig.1 Slippage correlation method

2) Matched filtering synchronization acquisition : Matched filtering synchronization acquisition (MFSA) is shown in Fig.2. In frequency parallel searching acquisition, M (M is the total number of hopping frequencies) frequency synthesizers are controlled to emit M frequencies. For frequency parallel searching acquisition, acquisition time is one hop While M DMFs are needed, which costs too much hardware resources.

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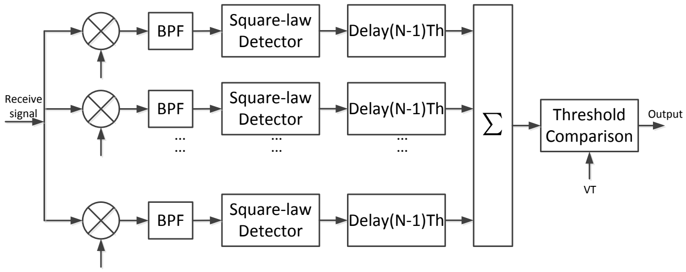

Fig.2 Matched filtering method

B. *Single-Channel Matched Filtering Algorithm*

Given the disadvantages of traditional synchronization acquisition methods, this paper presents a novel algorithm: Single-channel matched filtering (SC-MF) algorithm. This novel algorithm only searches once while the sliding correlation method searches constantly through changing phase. Furthermore, the SC-MF method decreases the complex hardware resources. In addition, this new algorithm can be compromise the false alarm probability and the synchronization probability through changing the decision threshold and dwell-time.

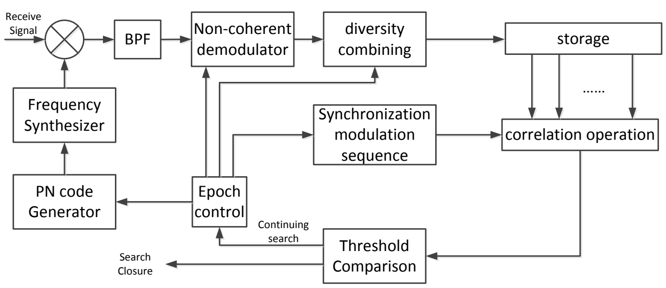

Fig.3 Single-channel matched filtering method

The diagram of the novel acquisition method is shown in Fig.3. In the new algorithm, a carrier signal modulated by a pseudo-random sequence, is introduced. And the modulating sequence is already known to the receiving end. The modulated carrier signal is sent out repeatedly to control the frequency hopping sequence. Furthermore, the parameters of synchronous header are as follows. For FFH/BFSK synchronization system, the synchronous header modulation sequence is $\mathrm{Pn}[k]$, k denotes its length. The frequencies of BFSK modulation signal are f_1 and f_2, T_h represents the frequency hopping interval. Diversity order is signified by L. The hopping frequency sequence modulated by $\mathrm{Pn}[k]$ is called a sub-synchronization header, and a synchronization header composed of R sub-synchronization headers, where $R \geq (KL+1)$.

Synchronization header and sub-synchronization headers structure are shown respectively in Fig.4 and Fig.5, where $K = 5, L = 3, R = KL + 1 = 16$.

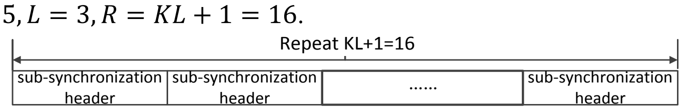

Fig.4 Synchronization header

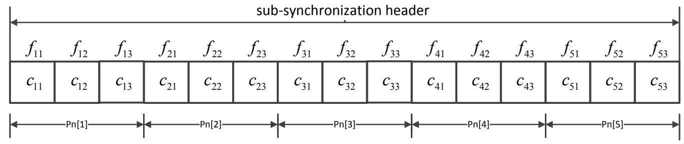

Fig.5 sub-synchronization header

For the receiver, we use the same hopping pattern as originating. The duration time of each frequency hopping point is $(KL+1)T_\mathrm{h}$. Such a long duration ensure a complete chip after mixing and filtering into the demodulator as long as there are hopping synchronization signals into the receiver.

III. Performance Analysis

A. *The Novel Acquisition*

As shown in the Fig.3, the received signal is given by

$$\begin{aligned} r(t) &= s(t) + n(t) \\ &= \sqrt{2}A\,cos(2\pi f_s t + \varphi) + \sqrt{2}n_i(t)\,cos(2\pi f_s t + \varphi) \\ &\quad -\sqrt{2}n_q(t)\,sin(2\pi f_s t + \varphi) \\ &= \sqrt{2}R(t)\,cos[2\pi f_s t + \varphi + \theta(t)] \end{aligned} \quad (1)$$

Where A is the amplitude of the signal, and $f_s, i = 1\ or\ 2$, is the modulation frequency of BFSK, and $n_i(t)$ and $n_q(t)$ are independent zero-mean white Gaussian noise with the same power spectral density as $n(t)$, And $R(t) = \sqrt{[A + n_i(t)]^2 + n_q(t)^2}$, $\theta(t) = tan^{-1}\frac{n_q(t)}{A+n_i(t)}$, the output of the square-law detector signal $y(t)$ is:

$$y(t) = x(t)^2 = R(t)^2 = [A + n_i(t)]^2 + n_q(t)^2 \quad (2)$$

$y(t)$ is distributed to the non-central chi-squared distribution with 2-degrees of freedom, its probability density function (PDF) is

$$p(x) = \begin{cases} \frac{1}{2\sigma^2} exp[-\left(\frac{y}{2\sigma^2} + \gamma\right)] I_0\left(2\sqrt{\frac{y\gamma}{2\sigma^2}}\right), & y \geq 0 \\ 0, & y < 0 \end{cases} \quad (3)$$

where γ is the signal to noise ratio:

$$\gamma = \frac{A^2}{N_0 B} = \frac{A^2}{\sigma^2}.$$

If there is no signal, the $y(t)$ is distributed to the central chi-squared distribution, and its probability density function(PDF) is

$$p(x) = \begin{cases} \frac{1}{2\sigma^2} \exp\left(-\frac{y}{2\sigma^2}\right)], & y \geq 0 \\ 0, & y < 0 \end{cases} \quad (4)$$

Assume that the sample time interval is $T = {}^{1}/_{B}$, the sample points are independent distribution. Therefore, the output Z of the integrator is:

$$Z = \frac{1}{\tau_d}\int_0^{\tau_d} y(t)d(t) \approx \frac{1}{N_B}\sum_{k=0}^{N_\mathrm{B}-1} y(kT) \quad (5)$$

where $N_{\mathrm{B}} = \frac{\tau_d}{T} = B\tau_d$. Based on the central limit theorem, Z is distributed to the Gauss distribution. So the probability density function(PDF) is gain as follows.

when signals present:

$$P_{\mathrm{H}_1}(Z) = \frac{1}{\sqrt{2\pi(4\sigma^2A^2+4\sigma^4)N_{\mathrm{B}}}} exp\frac{-[z-(A^2+2\sigma^2)N_B]^2}{2(4\sigma^2A^2+4\sigma^4)N_{\mathrm{B}}} \tag{6}$$

when signals do not present:

$$P_{\mathrm{H}_0}(Z) == \frac{1}{\sqrt{8\pi\sigma^4N_{\mathrm{B}}}} exp\frac{-[Z-2\sigma^2N_{\mathrm{B}}]^2}{8\sigma^4N_{\mathrm{B}}} \tag{7}$$

Consequently, we can calculate the false alarm probability (P_{FA}):

$$\begin{aligned} P_{\mathrm{FA}} &= \int_{\varepsilon}^{\infty} \frac{1}{\sqrt{8\pi\sigma^4N_{\mathrm{B}}}} exp\frac{-\left[Z-2\sigma^2N_{\mathrm{B}}\right]^2}{8\sigma^4N_{\mathrm{B}}} dZ \\ &= Q\left(\frac{\frac{\varepsilon}{2\sigma^2}-N_B}{\sqrt{N_{\mathrm{B}}}}\right) \\ &= Q(\beta) \end{aligned} \tag{8}$$

where $\beta = \frac{\frac{\varepsilon}{2\sigma^2}-N_{\mathrm{B}}}{\sqrt{N_{\mathrm{B}}}}$.

And the detection probability (P_{D}):

$$\begin{aligned} P_{\mathrm{D}} &= \int_{\varepsilon}^{\infty} \frac{1}{\sqrt{2\pi(4\sigma^2A^2+4\sigma^4)N_B}} exp\frac{-[z-(A^2+2\sigma^2)N_{\mathrm{B}}]^2}{2(4\sigma^2A^2+4\sigma^4)N_B} dZ \\ &= Q\left(\frac{\frac{\varepsilon}{2\sigma^2}-N_{\mathrm{B}}(1+\gamma)}{\sqrt{N_{\mathrm{B}}(1+2\gamma)}}\right) \\ &= Q\left(\frac{\beta-\gamma\sqrt{N_{\mathrm{B}}}}{\sqrt{1+2\gamma}}\right) \end{aligned} \tag{9}$$

The mean acquisition time is an important indicator in capture process. By using the flow signal technique in [7][8]and[9], the mean acquisition time is derived as follows:

$$E[T_{acq}] = \frac{1}{P_D}\left[1 + (1+kP_{\mathrm{FA}})\frac{v-1}{2}(2-P_D)\right]\tau_D, \tag{10}$$

where, $k \triangleq \tau_P/\tau_D$, τ_P represents the average penalty time, τ_D denotes the scanning dwell-time, v signifies the state number in a scanning period , and the classical algorithms have the same state number, $v = KL/\Delta$.

B. Synchronization Probability Comparison and False Alarm Probability Comparison

Because of the same scanning dwell-time and the integration time, the three algorithms have the same synchronization probability P_{D} and false alarm probability P_{FA}.

C. Mean Acquisition Time

1) SCSA algorithm: For the slippage correlation synchronization acquisition algorithm, the penalty time is $\tau_P = KLT_h$, $\tau_D = KLT_h$, and $v = KL/\Delta$. so the mean acquisition time $E[T_{acq}]$:

$$E[T_{acq}]_s = \frac{1}{P_D}\left[1 + (1+P_{\mathrm{FA}})\frac{\frac{KL}{\Delta}-1}{2}(2-P_D)\right]KLT_{\mathrm{h}}. \tag{11}$$

2) MFSA algorithm: in the matched filtering synchronization acquisition algorithm, the penalty time is $\tau_P = KLT_h$, the same as the slippage correlation , but the scanning dwell-time is shorter , that $\tau_D = \Delta T_h$, then $k \triangleq \tau_P/\tau_D = \frac{KL}{\Delta}$, $v = KL/\Delta$. So we have:

$$E[T_{acq}]_m = \frac{1}{P_D}\left[1 + \left(1+\frac{KL}{\Delta}P_{\mathrm{FA}}\right)\frac{\frac{KL}{\Delta}-1}{2}(2-P_D)\right]\Delta T_{\mathrm{h}}. \tag{12}$$

3) SC-MF algorithm: From the above analysis, the novel acquisition algorithm's mean acquisition time can be calculated as follows. $\tau_P = KLT_h, \tau_D = \Delta T_h$, and $v = (KL+1)/\Delta$.

$$E[T_{acq}]_n = \frac{1}{P_D}\left[1 + \left(1+\frac{KL}{\Delta}P_{\mathrm{FA}}\right)\frac{\frac{KL+1}{\Delta}-1}{2}(2-P_D)\right]\Delta T_{\mathrm{h}}. \tag{13}$$

IV. Result Analysis

A. Hardware Structure Comparison

Compare with Fig.1, Fig2 and Fig.3, the SC-MF algorithm structure is more simpler than MFSA algorithm, and compared to SCSA algorithm, the novel algorithm only have one more storage module.

B. Synchronization Probability (P_D) and False Alarm Probability(P_{FA})

As already analyzed, the three algorithms have the same P_{D} and P_{FA}.

C. Mean Acquisition Time Analysis

Compare with (11), (12) and (13), we can know that the mean acquisition time of the matched filtering synchronization acquisition algorithm and the novel acquisition algorithm is. almost equal when KL is far greater than 1 ($\mathrm{KL} \gg 1$) (this condition is always satisfied in practice).

Because of KL $\gg 1$, so

$$E[T_{acq}]_m \approx E\left[T_{acq}\right]_n \tag{14}$$

Because of:

$0 < P_D < 1, 0 < P_{FA} < 1$,

$(1+KL/\Delta P_{\mathrm{FA}})\frac{KL/\Delta-1}{2} \gg 1, (1+P_{\mathrm{FA}})\frac{KL/\Delta-1}{2} \gg 1,$,

Then, we gain:

$$\begin{aligned} \frac{E[T_{acq}]_m}{E[T_{acq}]_s} &= \frac{\frac{1}{P_D}\left[1+(1+KL/\Delta P_{\mathrm{FA}})\frac{KL/\Delta-1}{2}(2-P_D)\right]\Delta T_{\mathrm{h}}}{\frac{1}{P_D}\left[1+(1+KL/\Delta P_{\mathrm{FA}})\frac{KL/\Delta-1}{2}(2-P_D)\right]KLT_{\mathrm{h}}} \\ &= \frac{\left[\frac{1}{2-P_D}+(1+KL/\Delta P_{\mathrm{FA}})\frac{KL/\Delta-1}{2}\right]\Delta}{\left[\frac{1}{2-P_D}+(1+P_{\mathrm{FA}})\frac{KL/\Delta-1}{2}\right]KL} \\ &\approx \frac{(1+KL/\Delta P_{\mathrm{FA}})\frac{KL/\Delta-1}{2}}{(1+P_{\mathrm{FA}})\frac{KL/\Delta-1}{2}} \\ &= \frac{\Delta+KLP_{\mathrm{FA}}}{KL+KLP_{\mathrm{FA}}} \\ &\approx \frac{KLP_{\mathrm{FA}}}{KL+KLP_{\mathrm{FA}}} \\ &= \frac{P_{\mathrm{FA}}}{1+P_{\mathrm{FA}}} \end{aligned} \tag{15}$$

In equation (15), when the false alarm probability is $P_{FA} \to 1$, the mean acquisition time of the slippage correlation synchronization acquisition algorithm is twice as long as the mean acquisition time of the matched filtering synchronization acquisition algorithm. When $P_{FA} \to 0$, the advantage of the matched filtering synchronization acquisition algorithm is more significant. And the simulation result is shown as follows.

In Fig.6, we provide simulation results of the proposed system. From the comparison of the three curves, we can find out that the new algorithm saves a lot of time compares with sliding correlation method.

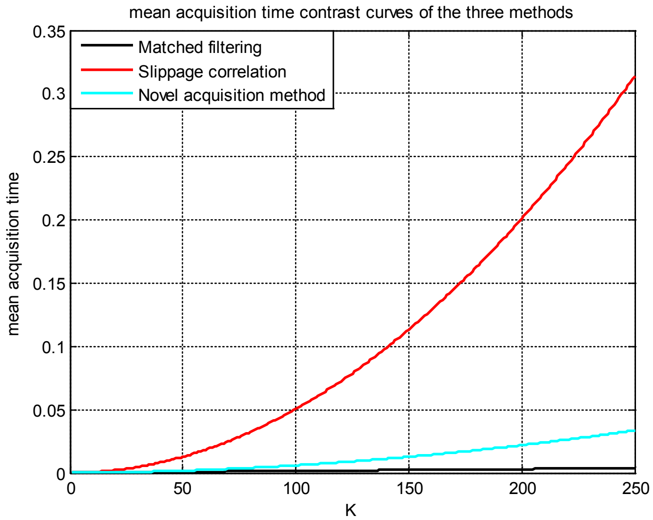

Fig.6: Mean acquisition time contrast curves

However, it is important to consider the delay of the system, the store time of the storage and the operation time of the correlation. Then these factors can increase capture time of the new algorithm, but does not affect the performance of rapid capture in practice.

V. CONCLUSIONS

In this paper, a novel acquisition algorithm is presented. Combined with the matched filtering synchronization acquisition algorithm which has advantages in acquisition time, the proposed algorithm is simple and easy to realize. Meanwhile, the new method has high acquisition probability and low false alarm probability. In addition, the new method decreases the complexity of the system , which can reduces hardware resources.

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