FAST ACQUISITION ALGORITHM FOR HYBRID DS/FH RECEIVER

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ABSTRACT

This paper introduced a fast scanning and waiting acquisition method for a DS/FH receiver used in the telemetry field. Mathematic model of the hybrid DS/FH system's acquisition process is given and discussed. The average acquisition time expression using this method and generalized average acquisition time formula is derived also. The validity of the proposed algorithm is verified after simulation. In the circumstances of Additive Gauss White Noise for the channel, simulation result at E_c/N_0= -15dB shows that the average acquisition time is decreased almost 4 times than that of waiting and searching method.

KEYWORDS

Telemetering, Spread spectrum, Synchronization, Frequency identification

I. INTRODUCTION

Hybrid direct sequence/frequency hopping spread spectrum (DS/FHSS) has received increased attention in the last decades, because it combines the advantages of both DS and FH spread spectrum systems, such as high anti-interference capabilities, while avoiding some other shortcomings. In this paper, a receiver with DS/FH techniques used in telemetry is evaluated.

Fast synchronization plays a very important role in the receiver, and two processes are performed: acquisition and tracking. Main purpose of this paper is to study on the acquisition. A typical acquisition technique called waiting and searching method is presented in some papers[1]: at first, the receiver's synthesizer is controlled to emit a certain frequency. When the receiving signal with the corresponding frequency occurs, an intermediate frequency signal is obtained, after DS demodulation, we can get the receiver's synthesizer information, and the receiver's synthesizer start emitting frequencies changing according as it. In this method, when the selected frequency is disturbed deeply, the acquisition becomes impossible, and when it's a long period of the FH, it will cost more time too.

To overcome the demerits of the acquisition method described above, a combined fast scanning and waiting method used for acquisition of Hybrid DS/FH system is proposed. In this method, local frequency synthesizer works at the fast scanning mode at first, the frequency's hopping rate is higher than incoming one's to match with the incoming frequency. When matches, synthesizer steps into waiting mode immediately, and when get the synchronization information from the DS demodulation system, the local synthesizer's hopping rate is changed to normal to match with the hopping rate of the transmitters. In this way, the acquisition time can be reduced remarkably compared with the waiting and searching method

This paper is organized as below: the study background, the current research result and the content of this paper is briefly introduced in section I. In section II, the combined fast scanning and waiting acquisition method is illustrated. The following section discusses the algorithm for calculating the average acquisition time with this method. In Section IV, simulation shows that with the new method, the average acquisition time is decreased significantly. Section V draws the conclusion in the final.

II. COMBINED FAST SCANNING AND WAITING ACQUISITION METHOD

The proceeding of the DS/FH synchronization can be divided into two steps: acquisition and tracking. The waiting and searching method of acquisition is always being used in the DS/FH receiver: a certain frequency is produced by the local synthesizer at first, when matched with the incoming signal's frequency, after mixing and filtering, an IF signal can be got, and is sent to the A/D converter, which is connected to the DS acquisition, tracking and demodulation circuit. When get the synchronization information after demodulation, the synthesizer will transmit the frequency patterns matched with the transmitters, and hop in the same phase and rate[2].

The acquisition can be realized very fast using the waiting and searching method, but it will take a long time if the period of the frequency pattern is very large. A combined method of fast scanning and waiting method is introduced here, in this way, the local synthesizer works in three modes: the local synthesizer works in a fast scanning mode at first, the hopping rate of the frequency produced by the local synthesizer is 4 times of the incoming ones; when match with the incoming signals, it steps into the waiting mode, after getting the synchronization information, it steps into the normal rate as the incoming ones according to the synchronization information. For example, the incoming signal's frequency pattern is as

$\{f_1,f_2,f_3,f_4,f_5,f_6,f_7,f_8,f_9,f_{10},f_{11},f_{12},f_{13},f_{14},f_{15},f_{16}\}$, the local frequency pattern is the same but the hopping rate is 4 times of the incoming ones, so interval of each hop of the incoming signal is T times, and interval of each hop of the local signal is T/4. As shown in figure 1, when the incoming signal's frequency pattern is as f_6, f_7, f_8□, and the local one is as f_1', f_2', f_3', f_4', f_5', f_6', f_7', f_8' □. At first, the frequency of the incoming signal is f_6, and the local one is f_1', after mixed, the signal is filtered by the low pass filter(LPF), so there is no signal output can be sent to the DS circuit, and it also can not get the correlation peak after the DS acquisition. Then the local synthesizer hops to f_2', no correlation peak too. After time of T+2T/4, the incoming frequency matches with the local one (f_7 and f_7'), after been mixed and low pass filtered, an IF signal appears, and is sent to the DS acquisition circuits. When get correlation peak, it is still cannot say that the acquisition part is finished, maybe it's a fake one, so it needs to be testified, means after 2-3 DS PN code periods continuously, if the correlation peaks all exceed the threshold, the acquisition of the FH period is finished, the local frequency hops to f_8' instantly, steps into the waiting method, and wait until the synchronization information got from the demodulated basic signals, then the local synthesizer's hopping rate changed to normal accord as the synchronization information. In this way, the acquisition time of the FH part can be reduced apparently.

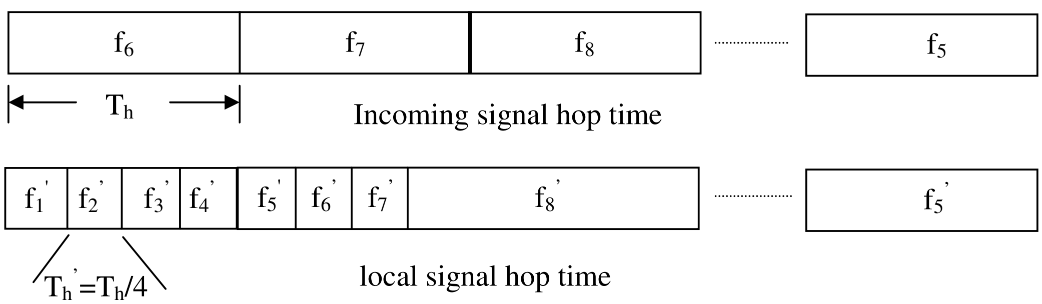

Fig.1 Demonstration of fast scanning and waiting acquisition method

III. MEAN ACQUISITION TIME CALCULATION

The mean acquisition time is a crucial parameter to measure the synchronization performance of a DS/FH receiver which can be calculated through a state shift map. The state shift map of the combined fast scanning and waiting method is shown in figure 2. It is assumed that there are N frequencies in this DS/FH system altogether, the period of the DS pseudo noise(PN) code as M, and each DS state shift time as T_s, the transmitter's frequency pattern as "f_1, f_2, f_3, …… , f_N". The receiver's frequency pattern should be as "f_1', f_2', f_3', …… , f_N'" when matches with the transmitter. Acquisition starts from time t=0, Assume the state is as S_{FH1}, in which receiver's frequency as f_1' and the transmitter's frequency as f_1, the probability of the state shift from S_{FH1} to S_{DS1} is $P_{FH1}=1/N$, and the probability of the state shift from S_{DS1} to S_{DS1c} is $P_{DS1}=1/2M$. If there is no interference, state shift from S_{DS1c} to the acquisition state W in route P_dT_s, in which, P_d means the detection probability of the DS acquisition. When there is interference, the state S_{DS1c} will be shifted to state S_{DS2} in route of $(1-P_d)T_s$, when testified as non synchronization, states shift to S_{DS3} in route of $P_{fa}T_s^{K+1}+(1-P_{fa})T_s$, P_{fa} means the false alarm probability of the DS acquisition, K means K times of shift from S_{DS2} to S_{DS3}. By the same token, the state shift function from S_{DS1c} back to S_{DS1c} through S_{DS2} … S_{DS2M} is

$$S_{DS1c} = B(T_s)S_{DS1c} + P_{DS1}S_{DS1} \tag{1}$$

$$B(T_s) = (1-P_d)T_s[A(T_s)]^{2M-1} \tag{2}$$

$$A(T_s) = [P_{fa}T_s^{K+1} + (1-P_{fa})T_s] \tag{3}$$

The shift function from S_{DS1} to W is

$$W = \frac{P_{DS1}P_dT_s}{1-B(T_s)}S_{DS1} \tag{4}$$

And from the figure 2, we can get $S_{DS1} = P_{FH1}S_{FH1}$, and (4) can be rewritten as

$$W = \frac{P_{DS1}P_{FH1}P_dT_s}{1-B(T_s)}S_{FH1} \tag{5}$$

In the same way, the function of state from S_{FHj} (means receiver's frequency is $f_j^{'}$ and the transmitter's frequency is f_j) to W through S_{DSi} is

$$U_{ij} = \frac{P_{DSi}P_{FHj}P_dT_s}{1-B(T_s)} \qquad (i = 0,1,\ldots,2M-1\ ;\ j = 0,1,\ldots,N-1) \tag{6}$$

$P_{DSi} = 1/(2M-i+1)$ means Prior probability of the acquisition in state of S_{DSi}, $P_{FHj} = 1/(N-j+1)$ means Prior probability of the acquisition in state of S_{FHj}. And the shift function for S_{DSi} to $S_{DS(i+1)}$ can concluded from figure 2 as:

$$D_i = (1-P_{DSi})A(T_s) \tag{7}$$

When receiver's frequency is $f_j^{'}$, but the transmitter's frequency isn't f_j, with the influence of the false alarm, state S_{FHj} shifted to $S_{FH(j+1)}$ through g1 times DS state shifts, the shift function can be written as:

$$E_j = (1-P_{FHj})[P_{fa}T_s^{K+1} + (1-P_{fa})T_s]^{g1} \qquad (j = 0, 1, 2, \ldots, N-1) \tag{8}$$

And

$$T_h^{'}(T_s) = [P_{fa}T_s^{K+1} + (1-P_{fa})T_s]^{g1} \tag{9}$$

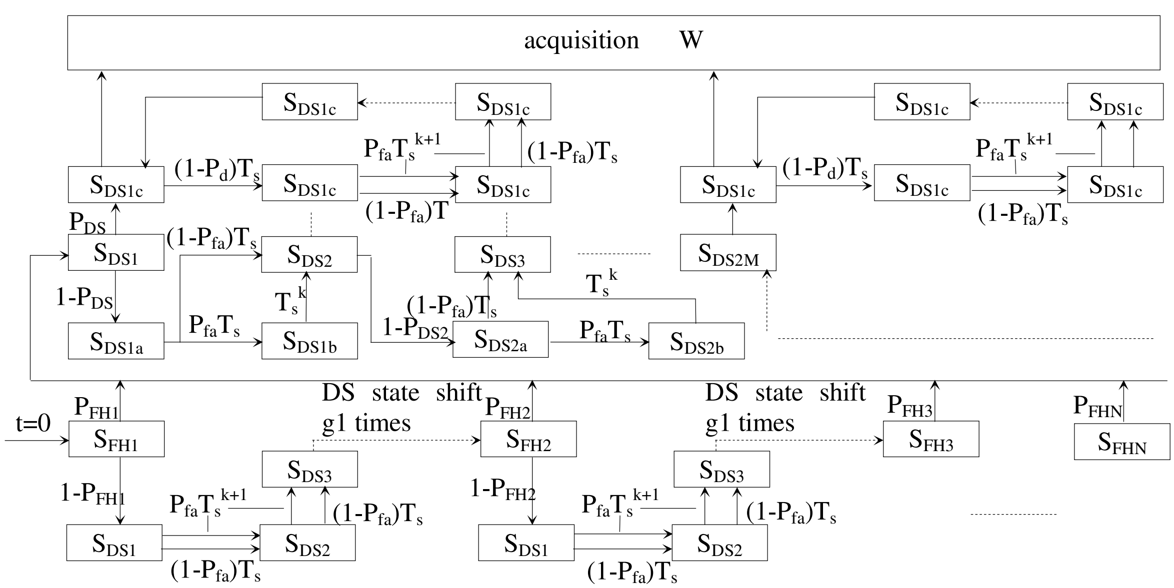

Fig.2 Demonstration of The state shift of the DS/FH signal's acquisition

The state shift process can be simplified as shown in figure 3. State shift function can be rewritten as:

$$Z(T_s) = U_{11} + D_1 U_{21} + ... + D_1 D + E_1 (U_{12} + D_1 U_{22} + ... + D_1 D_2 \cdots D_{2M-1} U_{2M2}) + \cdots + E_1 E_2 \cdots E_{N-1} (U_{1N} + D_1 U_{2N} + ... + D_1 D_2 \cdots D_{2M-1} U_{2MN}) \qquad (10)$$

With (6) and (7), (8) can be re written as:

$$Z(T_s) = \frac{1}{2M} \cdot \frac{1}{N} \cdot \frac{P_d T_s}{1-(1-P_d) T_s [A(T_s)]^{2M-1}} \cdot \sum_{j=0}^{N-1} \{[A(T_s)]^{g_1}\}^j \sum_{i=0}^{2M-1} [A(T_s)]^i \qquad (11)$$

Digital matched filter(DMF) is used here to realize the DS acquisition part, correlation one time in time of $T_c/2$, T_c means interval time of a PN code. Normalize T_s with $T_c/2$, and define $q_s = T_s/(T_c/2)$, the mean acquisition time of the DS/FH is

$$\overline{T}_{acq1} = \left.\frac{dZ(q_s)}{dq_s}\right|_{q_s=1} \cdot \frac{T_c}{2} = \frac{2+(2-P_d)(2M-1)(KP_{fa}+1)+(N-1)g_1 P_d (KP_{fa}+1)}{4P_d} \cdot T_c \qquad (12)$$

And from (9), we can get the relationship between Th' with g_1 as:

$$T_h' = \frac{g_1 (KP_{fa}+1)}{2} \cdot T_c \qquad (13)$$

Define $H=T_h/T_h'$, means the times of the receiver's frequency hopping rate to transmitter's. And (12) can be written as

$$\overline{T}_{acq1} = \frac{2+(2-P_d)(2M-1)(KP_{fa}+1)}{4P_d} \cdot T_c + \frac{(N-1)}{2H} \cdot T_h \qquad (14)$$

When H=1, means $T_h=T_h'$, the interval of the transmitter's one frequency hop equals to the receiver's, so we can get the mean acquisition time of the waiting and searching method as:

$$\overline{T}_{acq2} = \frac{2+(2-P_d)(2M-1)(KP_{fa}+1)}{4P_d} \cdot T_c + \frac{(N-1)}{2} \cdot T_h \qquad (15)$$

And from paper [3] [4], we can get the dectection probability and false alarm probability of the DS acquisition when using DMF as:

$$P_d = Q\left(\sqrt{\frac{2ST_c M}{N_0}}, \sqrt{\frac{2V_T^2}{N_0 M T_c}}\right) \qquad (16)$$

$$P_{fa} = \exp\left(-\frac{V_T^2}{2\sigma_n^2}\right) \qquad (17)$$

S is the power of the signal, N_0 means power spectral density of white gauss noise, V_T is the threshold of the DS acquisition, and $\delta_n^2 = N_0 M T_c/2$ is the variance of the noise.

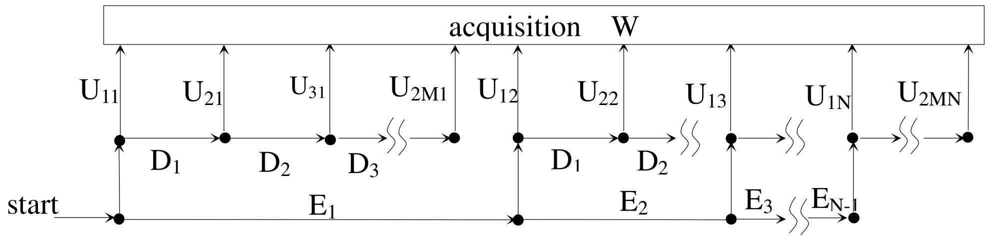

Fig.3 Simplified acquisition state shift diagram

IV. SIMULATION

Assume the characters of the DS/FH system as: frequency hopping rate 600hop/s, T_h=(1/600)s, PN code rate 4.9152MHz, T_c=(1/4.9152)*10^{-6}s, K=100, M=255, N=20, E_c/N_0 ($E_c = ST_c$) as variable, normalize the threshold as V_n ($V_n = V_T^2 / \sigma_n^2$), for simplification, define $T_h^{'}$ as the DS acquisition time, (14) presents the DS mean acquisition time when N=1. Define E_c/N_0 = -15dB, from (14) (15) (16) (17), we get the simulation result shown in figure 4. The mean acquisition time in the fast scanning and waiting method is about more than 4 times less than the one in waiting and searching method with Vn's value in the period of 5 to 70. But when Vn is larger than 80, the mean acquisition times in the both method are all increased, that's because when threshold augments to a certain value, the detection probability will decrease with the increase of the threshold rapidly.

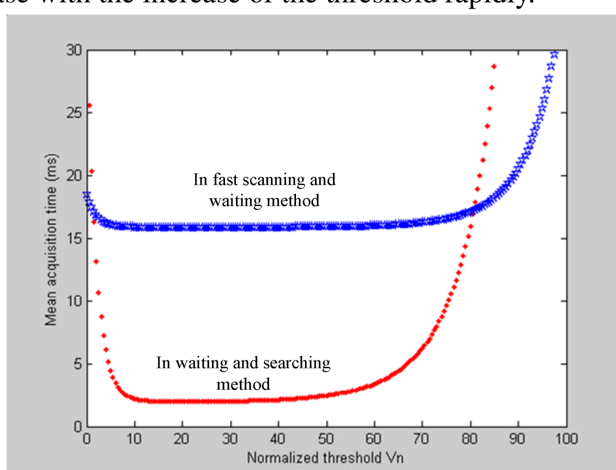

Fig.4 Mean acquisition time vs normalized threshold in SNR=-15dB

V. CONCLUSION

By combines the advantages of both DS and FH spread spectrum systems, while avoiding some other shortcomings, the hybrid DS/FHSS has received increased attention in recent years. In this paper, a fast acquisition method for a DS/FH receiver used in the telemetry field is proposed. The mean acquisition times in the fast scanning and waiting method and is the waiting and searching method are all presented. The simulation shows that in the fast scanning and waiting method proposed in this paper, the mean acquisition time is about more than 4 times less than the one in the waiting and searching method, in the circumstance of white guess noise with S/N_0 = -15dB. These analyses can be provided for the practical application scenario in telemetry field.

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