Automatic Recognition of Follower Jamming of Frequency-Hopping Communication

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***Abstract*—The follower jamming has a strong threat to the Frequency Hopping (FH) communication. Before the follower jamming is suppressed, the correct recognition of follower jamming should be completed. In this paper, the Frequency Hopping-Gaussian filtered minimum shift keying (FH-GMSK) communication system is adopted as the carrier to research the follower jamming recognition of FH communication system. The automatic recognition of the follower jamming in the FH communication system is proposed by a set of feature parameters which are robust and insensitive to the jamming to signal ratio（JSR）. This feature parameters can jointly extract the characteristics of the follower jamming in time，frequency and time-frequency at the conditions of no prior knowledge of the follower jamming. The simulated result shows that the correct recognition rate in FH communication system of the common follower jamming signals based on the method proposed in the reasonably high in the different JSR.**

Keywords-component*: *frequency-hopping communication, GMSK modulation, feature extraction, Follower jamming recognition.

I. INTRODUCTION

Frequency-hopped spread-spectrum (FHSS) systems are used extensively in military communications to neutralize the effects of various types of intentional jamming, The follower jamming is a correlative jamming of FH communication. When the hop rate was be tracked by the jammer, the FH communication can be strongly effected of the follower jamming. Recently, it is reported that the ferret receiver has been appeared which can monitor 80 channels at the same time and the scanning speed is 80,000 channels per second, the intercept probability of this receiver which in a certain frequency hopping speed is up to 100%. It is the most ideal interference means of FH communications. Many researchers have the interest to the follower jamming suppression [1-6]. But before the follower jamming is suppressed, the correct recognition of follower jamming should be completed.

The main researches of interference recognition are focus on the radar signal [7-8] and direct sequence spread spectrum (DSSS) system [9-11]. The recognition of follower jamming in FH communication has been rarely researched in the open literature.

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In this paper, The FH-GMSK communication system is adopted as the carrier to research the follower jamming recognition of FH communication system. The automatic recognition of the follower jamming in the frequency-hopping communication system was proposed by a set of feature parameters which are robust and insensitive to the jamming to signal ratio（JSR）. These feature parameters can jointly extract the characteristics of the interference in time，frequency and time-frequency at the conditions of no prior knowledge of the interference. Adopting the above parameters, the automatic recognition of the follower jamming was designed. The principle and classification step are discussed, to the end of the chapter, the simulated result and correlate conclusion are given.

II. SYSTEM DESCRIPTION

In the receiver ends of FH communication, the different antennas are adopted to isolate the FH signal and follower jamming signal in the airspace-frequency, Before the signals are de-hopped, the time delay estimation of every hop of the receiver signal (not the FH signal), if the time delay is less than the hop duration, we can know that the FH communication is followed by the follower jamming possibly. The time delay estimation method is researched in the other paper of writer. The main research point of this paper is to identify the specific types of follower jamming. When the time delay estimation is completed, the received signal and the pseudo-random sequence through the mixing and finish the de-hopping and the follower jamming recognition is realized in the intermediate frequency. Before the investigations of follower jamming recognition, the common types and models of follower jamming in FH-GMSK communication should be classed and built. The Figure 1 shows the sketch map of the recognition of follower jamming.

III. MODOL OF FOLLOWER JAMMING SIGNAL

According to the generation method, the follower jamming can be divided into the modulation and the non-modulation follower jamming. The modulation follower jamming contains the analogue modulation and digital modulation, the non-modulation is the CW (continuous wave) follower jamming.

1) CW follower jamming: The CW signal was modulated by the FH carrier.

2) Analogue Modulation follower jamming: The narrowband noise was modulated by the AM or FM, and transmitted by mixing with the FH carrier signal. In the FH-GMSK communication system, the modulation follower jamming is the FM.

3) Digital modulation follower jamming: The random code was modulated by the digital modulation, and transmitted by mixing with the FH carrier signal. In the FH-GMSK communication system, the modulation follower jamming is the FSK, MSK and GMSK.

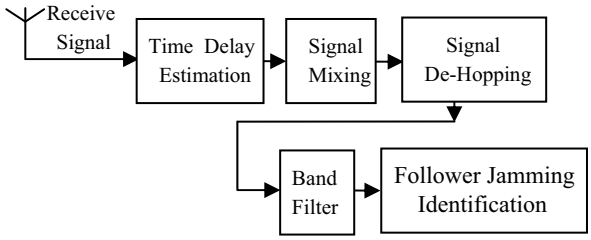

Figure 1 Block diagram of follower jamming identification

IV. RECOGNITION ALGORITHM OF FOLLOWER JAMMING

After the de-hopping, the follower jamming signal was considered as the narrowband signal, so the types of follower jamming recognition can be converted to the modulation recognition in background of noise.

A. Feature extraction of the Follower jamming

The extraction and calculation of feature parameters is the key of pattern recognition. The purpose of feature extraction is to get the group of classification features by extracting the different information. Because of the diversity, time-dependent behavior and time-dependent behavior in the follower jamming, the feature parameters can jointly extract the characteristics of the follower jamming in time，frequency and time-frequency at the conditions of no prior knowledge.

Before the recognition, the pretreatment should be filtered to the follower jamming signal. Sometimes, the bandwidth and carrier frequency should be estimated when the feature parameters are calculated. The accuracy requirement of feature parameters calculating are undemanding, normally the 10% is enough. Based on the method from literatures [13], the specific method and steps are as followed:

(1). Applying Fourier Transform to the received signal $s(n)$, and getting the $S(n)(n=0,1,\cdots,N-1)$, the signal is the analytic signal.

(2). Choosing the proper threshold, as the figure 2 shows, after the simulation, we choose 1/4 of the highest spectral line T_{sn} can satisfy the demand of algorithm.

(3) Searching the $S(n)$ from N=1 to N/2, if the continuous four points are greater than the threshold, marking this location f_1, The same procedure to search the $S(n)$ from N to N/2, if the continuous four points are greater than the threshold, marking this location f_2, so we can get the bandwidth $T_{bw}=f_2-f_1$ and carrier frequency $\hat{f}_c=(f_1+f_2)/2$.

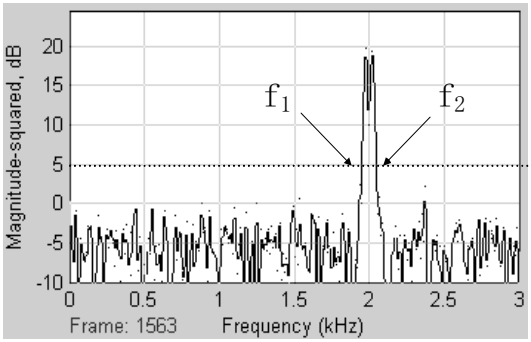

Figure 2 Estimation of carrier wave and signal bandwidth

The FH-GMSK communication system is adopted as the carrier to research the follower jamming recognition of FH communication system. According to the characteristic of GMSK modulation, the follower jamming was implemented to FH-GMSK communication system can adopt the modulation of FM, FSK, MSK and GMSK. The issue of modulation recognition has a lot of research, we select the following feature parameters to identify the follower jamming in the FH-GMSK communication system.

1) The factor of CW

The factor of CW was designed to the ratio of the largest and the second largest value of the power spectrum. Which can describe the outburst degree of the spectral line, when the CW greater than the threshold, we can judge that the CW follower jamming was existed. The figure 3 shows the CW versus JSR for CW, FM, 2FSK, MSK, GMSK.

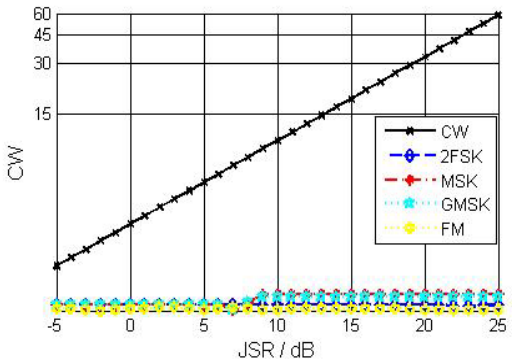

Figure 3 CW versus JSR for CW, 2FSK, MSK,GMSK

From the Figure 3, selecting the proper threshold, The CW follower jamming and modulation follower jamming can be separated by the parameter of CW.

2) Flatness factor[14]

The flatness factor can describe the undulation state of spectrum, the definition are as follows:

$$F = \frac{(P_1 + P_2)}{P_0} \tag{1}$$

$$\begin{cases} P_0 = \max\left|X(f_c)\right|^2 \ (\left|f - f_c\right| < B_w / 8) \\ P_1 = \max\left|X(f_c)\right|^2 \ (f_c - \dfrac{3B_w}{8} < f < f_c - \dfrac{B_w}{8}) \\ P_2 = \max\left|X(f_c)\right|^2 \ (f_c + \dfrac{B_w}{8} < f < f_c + \dfrac{3B_w}{8}) \end{cases} \tag{2}$$

$X(f_c)$ is the frequency domain of follower jamming signal, f_c is the carrier frequency or multiplication frequency of estimation, B_w is the bandwidth of estimation.

In this paper, the flatness factor of power spectrum is be defined as F_1, if the spectrum of follower jamming is flatness $F \approx 2$, if the spectrum is the single peak $F < 2$, if the spectrum is bimodal $F > 2$. The figure 4 shows the F_1 versus JSR for 2FSK, MSK , GMSK, From the Figure 4, Selecting the proper threshold, The FSK and FM, GMSK, FM follower jamming can be separated by the parameter of F_1.

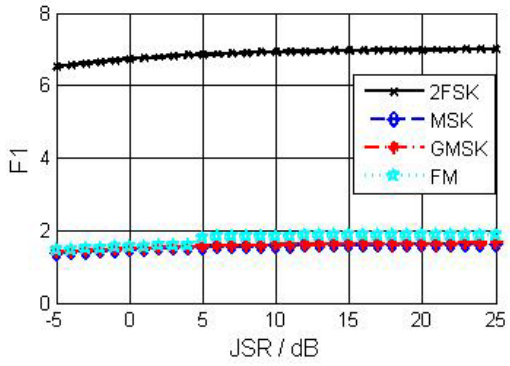

Figure 4 F_1 versus JSR for 2FSK, MSK,GMSK,FM

FM modulation is difference from the MSK and GMSK modulation in the, The flatness factor of quadratic spectrum F_2 was be selected to separate the FM modulation and MSK, GMSK modulation. The figure 5 shows the F_2 versus JSR for FM, MSK, GMSK, From the Figure 5, Selecting the proper threshold, The FM and MSK, GMSK follower jamming can be separated by the parameter of F_2.

3) Fractal box dimension of instantaneous phase *Frac*

GMSK signal is be realized by adding the Gaussian low pass filter to the input data of MSK, The MSK and GMSK signal can be separated from the input data in the theoretically analysis. The instantaneous phase can be used to reflect the feature of input data. In this paper, the fractal box dimension of instantaneous phase was selected to show the complexity of input data[12]. In the realization, extracting the instantaneous phase of MSK and GMSK signal, and then fractal box dimension value of instantaneous phase was be calculated. From the figure 6, selecting the proper threshold, The MSK and GMSK follower jamming can be separated by the parameter of *Frac* . The threshold value can be decided as follows.

$$Th_{Frac} = \frac{mean(D_{MSK}) - mean(D_{GMSK})}{2} + mean(D_{GMSK}) \tag{3}$$

$mean(D_{MSK})$ and $mean(D_{GMSK})$ are the mean value of the fractal box dimension to instantaneous phase of MSK and GMSK modulation.

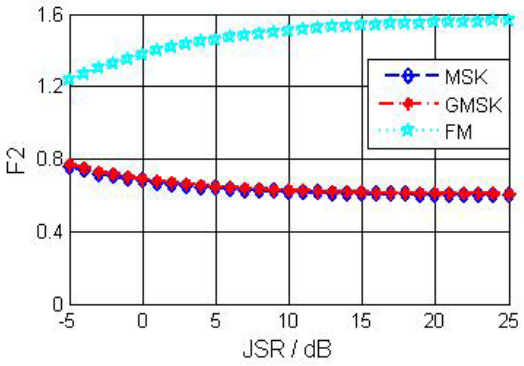

Figure 5 F_2 versus JSR for FM, MSK, GMSK

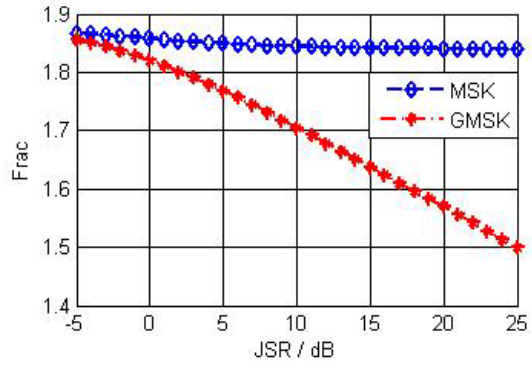

Figure 6 Frac versus JSR for MSK, GMSK

B. Auto-recognition scheme of the Follower jamming

According to the above analysis, if the FH signal was followed by the follower jamming, the follower jamming was de-hopping and through the band-pass filter can be regarded as the narrowband signal, calculating the feature parameters of the de-hopping follower jamming signal. By selecting the proper threshold, using the feature parameters of 1) ~3), the follower jamming can be recognized. In the figure 7 shows the identify flow of the follower jamming.

V. SIMULATION ANALYSIS OF COMPUTER

In the simulation, GMSK modulation is adopted to the FH communication, m sequence is selected to the pseudo random sequence, which the length is 63, the symbol rate is 1200bps, the hop rate is 200Hop/s, the number of FH is 64, channel intervals are 64, the FH communication and follower jamming module are built to the Simulink, follower jamming parameters are given to the Table 1.

As the Figure 7 shows, in the recognition, the threshold should be defined, in this paper, the thresholds are defined by

running 500 independence simulations, the feature parameters are given through the Table 2.

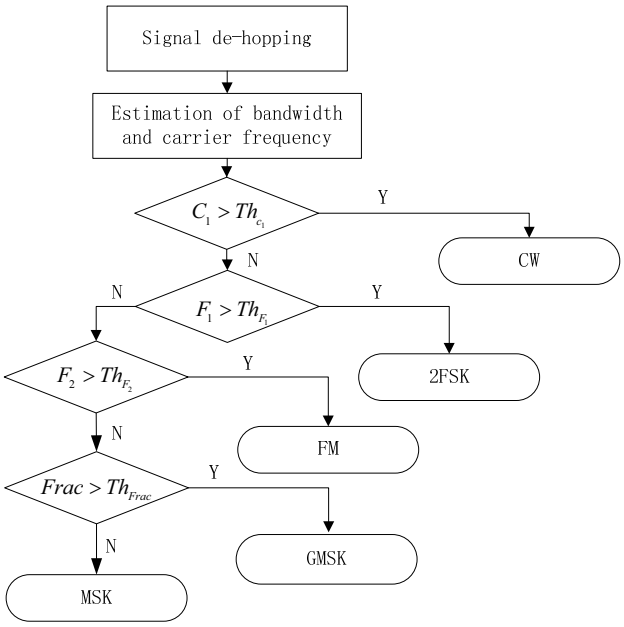

Figure 7 Flowchart for the Follower jamming recognition of FH-GMSK

Tab .1 Follower jamming parameters in the simulation

	Jammer type	Jammer parameter
Follower Jamming	CW	CW
	Analogue Modulation	FM
	Digital modulation	FSK, MSK, GMSK

Tab .2 Threshold of the feature parameters

Feature parameters	CW	F_1	F_2	Frac
Threshold	2.0	4.0	0.97	1.77

When the value of JSR are given from -5 dB to 25 dB , the value of SNR is given to 10 dB, The simulation is running 500 to the same JSR of every follower jamming. The recognized number of correct and error are being statistical to the common follower jamming of FH-GMSK communication, Figure 8 shows the correct recognition rate of the follower jamming of FH-GMSK communication.

The simulated result shows that the common Follower jamming of FH communication can be recognized simply and quickly of the recognition algorithm which is given in this paper. The total recognition rate is up to 96%. Meantime the recognition rate is not changed along with the JSR, The stability and applicability of recognition algorithm is well used.

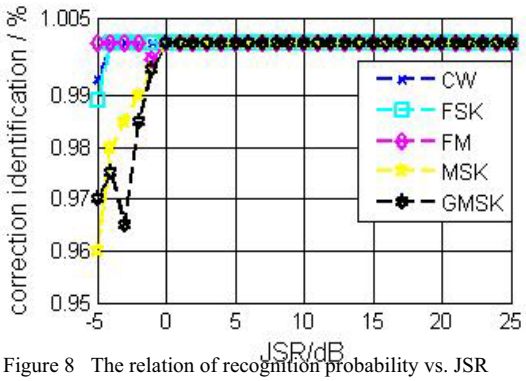

Figure 8 The relation of recognition probability vs. JSR at SNR =5dB

VI. CONCLUSION

The follower jamming have a strong threat to the FH communication, The premise of the follower jamming suppression is the correct classification and recognition., on the basis of recognition, the reasonable anti-jamming methods can be adopted to the FH communication. The follower jamming recognition is focused on this paper, the FH-GMSK communication system is adopted as the carrier to research the follower jamming recognition of FH communication system. The types of the follower jamming was be analyzed , The feature parameters characteristics were jointly extracted of the follower jamming in time，frequency and time-frequency, the classification method of hierarchical decision was be used to recognize the follower jamming of FH-GMSK communication system. The simulated result shows that the correct identification rate in FH communication system of the common follower jamming signals based on the method proposed in the reasonably high in the different JSR.

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