Adaptive Detection of an Unknown FH Signal Based on Image Features

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***Abstract*—We introduce an adaptive detection structure for unknown frequency hopping (FH) signal. After getting the short time Fourier transform (STFT) of received signal, we process the time-frequency spectrogram in terms of image operations, and extract multiple image features. Two kinds of method are employed for combinative detection. We firstly establish the FH signal verification and joint parameters estimation (FHSV-JPE) model based on these image features, and estimate some FH parameters while resolving the model. The FH detection threshold used in the model can be adjusted adaptively according to complicated time varying environments. Then we propose a time frequency (TF) matching method to further detect the jammed hops and estimate other FH parameters. Simulation results demonstrate that this detection algorithm is feasible and efficient.**

***Index Terms*—FH signal, Adaptive detection, Image feature**

I. Introduction

FH communication has received ever increasing attention as numerous applications have adopted this scheme. With this increased use of FH communications, naturally, came the question of detection. This question has given rise to a considerable amount research. Many new detection methods are proposed in recently years. The method described in [1] adopts exponential averaging algorithm to estimate and eliminate the interferences. Fast folding algorithm and time-frequency analysis are integrated in reference [2] to detect FH signals in low signal to noise ratio (SNR). However the above two methods can not eliminate short time burst signals. According to reference [3], array processing method was used to detect FH signal, but it is difficult to determine proper threshold in complicated channel. Reference [4] [5] introduced image processing into the FH detection, this kind of methods can eliminate some kinds of interferences effectively, but they didn't give out explicit ways to verify the existence of FH signals, and they cannot detect the hops jammed with frequency-fixed interferences [5].

This paper presents an adaptive detection method for FH signals in complicated channel environments. It adopts digital image processing to preprocess the TF spectrogram, establishes FHSV-JPE model and uses TF matching method for reliable detection, the proposed method can effectively eliminate burst interferences and detect the jammed hops of the FH signals. Fig. 1 shows the detection chart, the following sections will introduce signal model, feature extracting and adaptive detection method in turn. Simulation results and performance analysis are given at last.

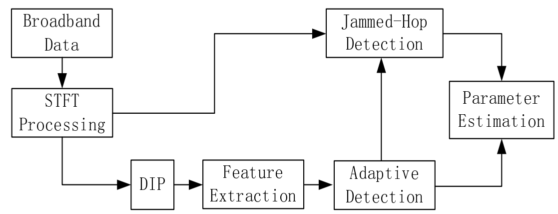

Fig. 1. The flow chart of the adaptive detection method

II. Signal Model and Preprocessing

The premise of FH signal detection is introduced firstly. The discrete model of broadband received signal is defined as

$$r(m) = s(m) + i(m) + n(m), \tag{1}$$

where $s(m)$ represents the unknown FH signal, $n(m)$ is the wideband noise which has different distributions in different time-frequency areas, $i(m)$ expresses the composite interference signal. It includes conventional modulated signals, short time burst signals, chirp signals and so on. The parameters of $s(m)$ are unknown, the range of its hop rate is the only needed information.

The STFT is chosen to preprocess the broadband received signal. The time-frequency spectrum of the signal can be obtained as:

$$Stft(m,k) = \sum_{n=0}^{N-1} r(n) w^*(n-m) e^{-j2\pi kn/N}. \tag{2}$$

In order to achieve reliable processing, proper time-frequency resolution and window function $w(m)$ should be chosen according to the range of hop rate.

III. Image processing and feature extracting

The amplitude of time-frequency spectrum can be regarded as an image, therefore, image processing methods can be adopted to acquire image features. The operations of image processing are orderly introduced as follow.

The signal existence area of the image is our analysis focus, which can be obtained by image segmentation. We present a new image segmentation method based on Neyman-Pearson (NP) rule [6]. It can be defined as

$$Sbin(m,k) = \begin{cases} 1, & |Stft(m,k)|^2 \geq \mu \\ 0, & |Stft(m,k)|^2 < \mu \end{cases}, \mu = -ln(\alpha_0)\lambda_{m,k}, \tag{3}$$

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where $Sbin(m,k)$ expresses the binary image after segmentation, α_0 is the given false alarm probability, $\lambda_{m,k}$ represents the power of noise, it can be obtained by averaging the power of a certain region whose center is point (m, k).

After image segmentation, the mathematical morphology method is adopted to get rid of regions which contain frequency-fixed and burst interferences. Mathematical morphology is a nonlinear filtering algorithm whose basic operations are dilation ($\oplus$) and erosion ($\ominus$) [7]. Suppose the original image is A1 ($Sbin(m,k)$), four steps are taken to filter out interference regions,

$$\begin{cases} A2=(A1\oplus B1)\ominus B1, A3=A2-(A2\ominus B2) \\ A4=(A3\ominus B3)\oplus B3, A5=(A4\ominus B4)\oplus B4 \end{cases}, \quad (4)$$

where B1,B2,B3 and B4 are proper adopted structural elements according to hop rate. So we get the needed image A5, which only contains FH signal regions and interference regions which seem like hops of FH signal.

According to image A5, six features are abstracted. They are region center, region time length, region frequency height, decentralization degree, direction and region energy. These features respectively describe the time-frequency range, shape and energy information of those regions. Region center includes central time and central frequency; decentralization degree is a statistic feature which expresses the enriched degree; region direction describes the region gradient, which is obtained by the collection's moments. So each region can be expressed by a group of features. The first two features are mainly used to detect FH signal, the others are considered as judgment features to further eliminate interferences.

IV. Adaptive detection of FH signals

This section will gave out the adaptive detection method, two techniques are presented to detect the signals. The FHSV-JPE model is used to detect the un-jammed hops, which base on the extracted multiple features, and the TF matching method is used to detect the jammed hops of the FH signal, the strategy of the adaptive detection threshold is introduced at last.

A. FHSV-JPE Model

After image processing, those unconnected regions fall into two categories: most regions which represent the hops of FH signal and the others which caused by interferences. The former category has special characteristics as follow: central times of hop regions are at a distance of integral multiples of hop duration T_0; region lengths (hop duration) are almost equal, the average of region lengths is a constant (α) proportional to T_0; the central frequencies of adjacent hops would be different, all the central frequencies distribute in a fixed hop band. However the interference regions which seem like a FH hop have no obvious orderliness. Their region centers and time lengths can be considered as random uniform distributions in their permitted ranges.

According to practical circumstance, suppose that there are N_1 hops in the analyzed domain,the existence of FH signal can be determined if more than $M_L (M_L < N_1)$ hops are detected. Then the FHSV-JPE model which mathematically describes the problem can be established as follow:

FHSV-JPE model: supppose collection $A\{(a_n,b_n)\}$ has N elements, $a_n \in [0,T]$, T is the analyzed time length.A has two complementary subsets: FH collection A_1 with N_1 elements and interference collection A_2 with N_2 elements. Their points respectively satisfy (5) and (6),

$$A_1=\{(a_n,b_n)|a_n=n\cdot T_0+\tau+m_1, b_n=T_0\cdot\alpha+m_2\}, \quad (5)$$

$$A_2=\{(a_n,b_n)|a_n=m_3, b_n=m_4\}, \quad (6)$$

where T_0, α, τ are unknown constant parameters, $\tau\in[0,T_0]$, $\alpha \in [0.7T_0, 0.95T_0]$; m_1, m_2 are independent Gaussian random variables, $m_1 \sim N(0,\sigma_1)$,$m_2 \sim N(0,\sigma_2)$, σ_1,σ_2 are unknown constant parameters; m_3, m_4 are independent uniform random variables, $m_3 \sim U(0,T)$, $m_4 \sim U(0.65T_0, T_0)$.

Question:If collection A and parameters T, M_L are given, how to verify the existence of FH signal? How to estimate T_0, α ,τ and classify the collection A if FH signal exists?

The central time a_n and region length b_n are the two main features used in the model. m_1, m_2 express their random offsets between calculated and theoretic value, their variances σ_1,σ_2 relate to the time resolution and SNR. Optimal estimation will be achieved if we obtain accurate estimation of collection A_1. According to the resolving of the model, we can verify the existence of FH signal and estimate some FH parameters.

B. TF Matching Method

According to estimated parameters such as hop rate, hop time and FH bandwidth, we can determine the appear time, disappear time and frequency range of undetected (jammed) hops. Based on the linearity principle of STFT, the energy of jammed region contains hop energy and energy of frequency-fixed signal. Moreover, the power distribution of frequency-fixed signal is considered as stationary in the hop duration. Compared with other time-frequency region of the frequency-fixed signal, energy of jammed region is higher. From this characteristic, we can use TF matching to detect the jammed hops in time-frequency power spectrum.

If the nth hop is needed to be detected, whose center time is M_n, bandwidth is K_n(obtained by resolving the FHSV-JPE model), and the range of hop band is $[K_L, K_H]$. The TF template can be defined as

$$f_{tem}(m,k)=\begin{cases} 1, & m\in[M_n-T_0/2, M_n+T_0/2] \\ -1, & m\in others \end{cases}, \quad (7)$$

where $k\in[0,K_n]$ and $m\in[M_n-T_0,M_n+T_0]$. The TF spectrums which may contain the nth hop are processed by the formula

$$f_n(m,k)=\begin{cases} 1, & |Stft(m,k)|^2 < h \\ -1, & |Stft(m,k)|^2 \geq h \end{cases}, \quad (8)$$

where $k\in[K_L,K_H]$, $h=\sum\limits_{k=M_n-T_0}^{M_n+T_0}|Stft(m,k)|^2/(2T_0+1)$. The above processing firstly calculates the average power of a certain frequency line, then the average power is compared with the power of every point on the frequency line. If the frequency point belongs to the nth hop, $f_n(m,k)$ equals to 1 when $m \in [M_n - T_0/2, M_n + T_0/2]$, or $f_n(m,k)$ is -1. If the frequency point does not belong to the region of the nth hop, the value of $f_n(m,k)$ conforms to rand distribution.

At last the sliding correlation of $f_{tem}(m,k)$ and $f_n(m,k)$ can be achieved by

$$V_{cor}(k_i) = f_n(m,k) \otimes f_{tem}(m,k), k \in [K_L, K_H]. \quad (9)$$

Suppose K is the value of k_i when $V_{cor}(k_i)$ have its peak value. The frequency point K is just the beginning frequency of the nth hop. According to the signal bandwidth, the center frequency of FH signal can be determined.

C. Adaptive Threshold Adjusting

From the analysis in above subsections, we can determine the existence of the FH signal with detection threshold M_L, and adopt TF matching method to detect the other $N_1 - M_L$ jammed hops. But the number of jammed hops is uncertain under the time-varying environments, so the value of the threshold M_L should be dynamic and adaptive.

Under the assumption in above subsections, the feature point (a_n, b_n) which represents the nth hop will fall into an ellipse area whose center is $(nT_0 + \tau, \alpha T_0)$. We can set an allowable area with a given probability according to some apriori information, the nth hop is considered to be detected if the feature point falls into this area. Under above rule, if $M_d (M_d \geq M_L)$ out of N_1 hops are detected, we can set the M_d as the current detection threshold. Obviously, M_d reflects the influences of SIR, SNR and other frequency-fixed interferences on FH signals. The value of M_d will be adjusted automatic and adaptively to time varying environments. The detection and false alarm probability based on this threshold is described in another paper in detail. we can further measure the unknown FH parameters based on the adaptive detection method.

V. Simulation and Analysis

Simulation signal is generated according to received signal model. The hop rate of FH signal is 20hops/s, the hop band is set to be 512 KHz. There are 20 intact hops in simulated signal,three hops are randomly chosen and set to be jammed by frequency-fixed signal. The background includes lots of AM, MFSK, MPSK and MORSE interferences. Especially, twenty short-time burst interferences are included to testify the detection performance, the frequencies of the burst signals is random chose within the hop band, the lengths of the burst signals is adopted randomly in the scope $[0.7, 1.3]T_0$, the appear time of each burst signal is chosen randomly too. The SNR is set to be 15dB,and the SIR is set to be -10dB.

The time-frequency spectrogram of a simulated signal is shown in Fig. 2. We can see that several hops are jammed by frequency-fixed signals and there are lots of burst interferences in the hop band.After mathematical morphology processing, there are few interference regions remained, which is shown in Fig. 3. Therefore image processing can effectively eliminate the frequency-fixed interferences.

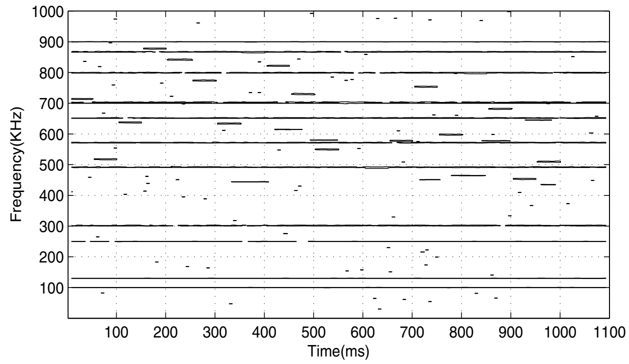

Fig. 2. Time-frequency spectrogram of a simulation signal

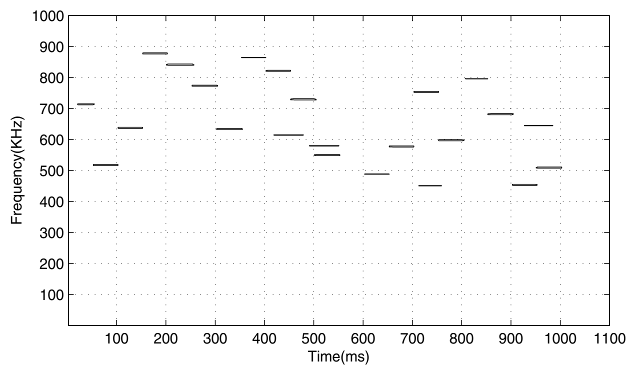

Fig. 3. Time-frequency spectrogram after image processing

Different from methods in [4][5], we extracts the image futures after image processing in order to carry out the signal detection and the parameter extraction. The recovered FH spectrogram is shown in Fig. 4, where the real lines stand for the hops detected by the resolving FHSV-JPE model (M_L =10), the dashed lines express the hops detected by TF matching method. The frequency estimation offset of each hop is less than 1500Hz.

The Monte Carlo simulation is carried out to test the detection performance of proposed algorithm. According to the simulation results shown in Table. I, the detection probabilities

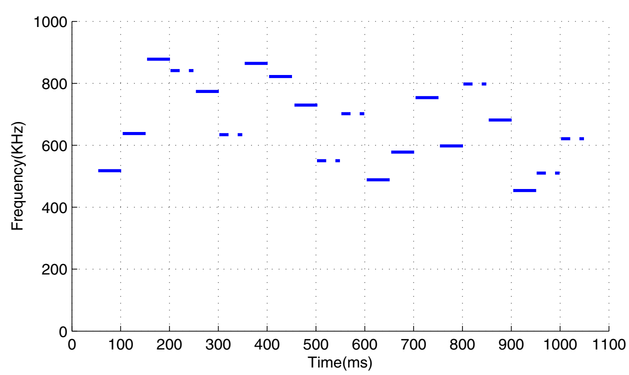

Fig. 4. The recovered spectrogram of FH signal

TABLE I
DETECTION PROBABILITY

Freq.Offset	FH signal	Un-Jammed hop	Jammed hop
1 KHz	100%	94.24%	83.33%
2 KHz	100%	97.35%	94.67%

TABLE II
ESTIMATION OF FH PARAMETERS

FH Parameters	Period (ms)	Bandwidth (KHz)	duration (ms)	Delay (ms)
Real Val.	50	512	45	47.5
Esti. Val.	50.04	451.08	47.45	48.40
Esti. Var.	0.08	16.42	1.50	1.25

of FH signal is 100%, and the detection probabilities of un-jammed hops higher than that of jammed hops. It is obvious that the jammed hops can be effectively recovered when the frequency estimation offset is less than 2000 Hz.

The estimation of FH parameters is shown in Table. II. The estimation of hop period parameter is very accurate, which is close to the real value. The estimated hop band value is smaller than the real value because the number of intact hops is relatively small in the analyzed domain. The image processing can effectively decrease the number of interfered hops, however it may bring the dilation of time-frequency image region [5]. So estimated value of hop duration parameter is bigger than its real value, and the estimated value of τ exists offset compared with the real value. The estimates of above two parameters have good consistency.

VI. CONCLUSION

In this paper a technique for detecting unknown FH signals in complicated environment was described. Compared with the methods proposed in recent papers, this multistep technique adopts FHSV-JPE model and TF matching method, which can effectively eliminate the burst interferences and reliably recover the hops jammed by frequency-fixed signals. Simulations demonstrate the efficiency of the proposed algorithm in complicated environments.

REFERENCES

[1] Brown,C ,Kowalske,K, Robertson,C, “Detection of Frequency-Hopped Wavefoms Embedded in Interference Waveforms”, *IEEE Military Communications Conference,(MILCOM 2005)*.

[2] Wang Guo-hua ,Yu Neng-hai,“FFA and TFA-Based Interception of LPI Frequency Hopping Signal”,*Journal of Electronics and Information Technology*,Vol.29 No.7,Jul 2007.

[3] MAO Guo-hua, WANG Ke-ren,“A Method of Detection of HF FH Signals Based on Array Signal Processing”,*Communication Countermeasures*,No.2 2007,Sum.97.

[4] CHEN Shuo,LI Tian yun,GE Lin dong,“Study on Frequency-Hopping Detection Algorithm Based on Edge Detection”,*Journal of Information Engineering University*,Vo1.7 No.3, Sep.2006.

[5] Xu Mankun, Ping Xijian, “A New Time-Frequency Spectrogram Analysis of FH Signals by Image Enhancement and Mathematical Morphology”, *International Conference on Image and Graphics 2007*.

[6] Thomas schonhoff, Arthur A. Gionlano, Detection and Estimation Theory and Its Applications[M], *Publishing house of electronics industy*.2007

[7] C.Gonzalez, Richard E.Woods, Digital Image Processing (Second Edition)[M], *Prentice Hall*, 2002