A New Parameter Estimation Method for Frequency Hopping Signals

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***Abstract*—A parameter estimation algorithm for multiple frequency-hopping (FH) signals based on maximum energy difference is proposed in this paper. First, the time-frequency (TF) matrix is obtained by TF analysis such as short-time Fourier transform (STFT) and smoothed pseudo wigner-ville distribution (SPWVD). Then, the carrier frequency and the TF data with valid frequency are determined according to the distribution of energy. Next, the number of signal segments and window length in each nonzero row of the TF data is obtained. Finally, hopping time and hop cycle are estimated based on the maximum energy difference. Simulation results indicate that the proposed algorithm has better anti-noise performance than the TF pattern modification method and the STFT-SPWVD method. The new method is suitable for asynchronous and synchronous network.**

I. INTRODUCTION

FH communication has been widely used in military fields because of a series of advantages, such as strong anti-jamming performance, low probability of interception, excellent security performance and so on, which promotes the research of FH communication reconnaissance technology [1]. The parameter estimation of FH signals is a precondition to obtain enemy intelligence or interfere accurately in the non-cooperative communication. FH signal is a typical non-stationary signal, whose carrier frequency is time-varying and pseudo-random. TF analysis methods are mostly used to estimate parameters. Traditional methods applied STFT, WVD, PWVD and SPWVD to FH signal parameter estimation [2-5]. Parameters are estimated by utilizing the periodicity of the envelope waveform formed by the maximums of TF distribution along frequency axis at each moment. Though the methods are simple, they have a low accuracy and poor performance when signal-to-noise ratio (SNR) is low. And they only can be applied to single FH signal. Fu et al used STFT and STFT-SPWVD to estimate parameters of multiple FH signals, respectively [6-7]. They think the number of signals and frequencies change at the moment of hopping. However, the performance is greatly affected by noise and only suitable for synchronous orthogonal network. Sha et al proposed a TF pattern modification method based on TF sparsity, which can obtain a clearer TF pattern [8]. But the parameters in optimization model are difficult to choose and have a great influence on the result. In order to improve the estimation performance under low SNRs, a novel hopping time and hop cycle estimation algorithm is proposed.

II. SYSTEM MODEL

Assume that N FH source signals are transmitted during the reception period Δt. The nth source signal $s_n(t)$ can be expressed as

$$s_n(t) = a_n(t)e^{j[\omega_n(t)t+\varphi_n(t)]}, n = 1, 2, \dots, N \qquad (1)$$

where $a_n(t)$ is the baseband complex envelope of $s_n(t)$. $\omega_n(t)$ and $\varphi_n(t)$ are carrier frequency and phase, respectively. Considering the single-antenna linear mixing model, the mixed signal received by a single antenna is

$$r(t) = \sum_{n=1}^{N} k_n s_n(t) + \sigma(t) \qquad (2)$$

where $r(t)$ is the mixture of received signals and noise, k_n is the amplitude attenuation coefficient of the nth signal and $\sigma(t)$ is the Gaussian white noise.

III. THE PROPOSED ALGORITHM

The spectrogram which represents the energy is used to obtain TF data. Spectrogram is defined as the square of the STFT module:

$$SPEC_s = |STFT_s(t, f)|^2 \qquad (3)$$

The TF matrix $TF(p, q)$ is obtained after TF analysis. $p = 1, 2, \dots, P$, $q = 1, 2, \dots, Q$, P and Q are the numbers of frequency points and windows. The sum of each row of data is calculated and denoted as $EN(p)$. Determine the number of carrier frequency N_f according to the amplitude and location of the peak point of the sum. Define the $(N_f + 1)th$ largest value in peak energy vector as η, and remove the row data composed of noise:

$$TF(p, :) = \begin{cases} TF(p, :) & EN(p) > \eta \\ 0 & EN(p) \le \eta \end{cases} \qquad (4)$$

where $TF(p, :)$ denotes the pth row of $TF(p, q)$. Then remove noise points for each nonzero row $p_j(q)$ of $TF(p, :), j = 1, 2, \dots, N_f$. Set a threshold, and set the energy to 0 that is less than the threshold:

$$\tilde{p}_j(q) = \begin{cases} p_j(q) & p_j(q) > \sigma_1 \max(p_j(q)) \\ 0 & p_j(q) \le \sigma_1 \max(p_j(q)) \end{cases} \qquad (5)$$

But (5) can not remove noise with very large amplitude. Then we can utilize maximum density to remove them.

The number of signal segments at a frequency can be got by d and a threshold σ_2. $d = \max(diff(\hat{\mathbf{q}}))$, $\hat{\mathbf{q}}$ satisfies $\tilde{p}_j(\hat{\mathbf{q}}) > 0$, $diff()$ denotes difference. If $d > \sigma_2 \text{mean}(diff(\hat{\mathbf{q}}))$, there is a noise segment between two signal segments.

According to the position of d, we can get the time vector $\hat{\mathbf{q}}_{pi}, pi = 1, 2, \ldots, n_p$ of each signal segment, n_p is the number of signal segments. The difference between the maximum and the minimum value in $\hat{\mathbf{q}}_{pi}$ is taken as the window length $wlen_{pi}$ of each segment.

Assume that a line h moves along the time axis, and there is a window on each side of h. The absolute value of the energy difference in the two windows reaches the maximum at the hopping time. For vector $p_j(q)$, the corresponding energy of the signal segment $\hat{\mathbf{q}}_{pi}$ is reserved, the energy of other segments is set to 0, and the following steps are performed:

1) Extend $1.5wlen_{pn}$ zeros before and after $p_j(q)$. q do the corresponding expansion $q' = 1 - \text{floor}(1.5wlen_{pi}) : Q + \text{floor}(1.5wlen_{pi})$;
2) The line h moves along the time axis and calculate the square of the energy difference ΔE in the windows;
3) The corresponding q' of peak point of ΔE^2 is estimated as hopping time;
4) Obtain hop cycle based on hopping time.

Perform above processing to each signal segment of each non-zero row in $p_j(q)$.

IV. SIMULATIONS AND ANALYSIS

STFT is applied in the experiment. Set $\varepsilon_1 = 0.5$ and $\varepsilon_2 = 8$. The relative error of hop cycle is defined as:

$$e = \frac{1}{R}\sum_{i=1}^{R}\frac{\left|\tilde{T}_i - T\right|}{T} \tag{6}$$

Where R denotes the number of experiments, $\tilde{T}_i$ and T denote the estimation and true value of hop cycle in the ith experiment, respectively.

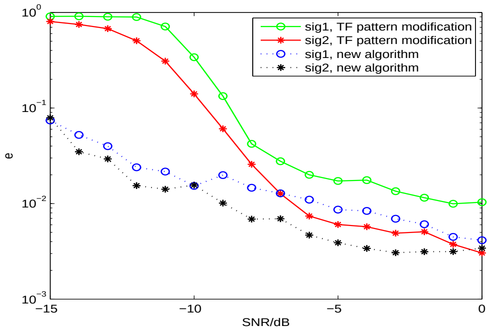

Fig. 1. Relative error curves of hop cycle estimation under different SNRs.

The estimation performance of the proposed method is compared with TF pattern modification method [8] in asynchronous network and the STFT-SPWVD method [7] in synchronous network, as shown in Fig. 1 and Fig. 2. The proposed algorithm has good anti-noise ability, and is suitable for asynchronous and synchronous network. The TF accuracy of STFT-SPWVD method is higher, so the estimation accuracy is better than the proposed method while SNR reaches a certain value. However the STFT-SPWVD method has large calculation amount and it is time-consuming. The accuracy of the proposed algorithm is limited by the accuracy of the TF analysis. The TF analysis method can be changed according to the actual needs.

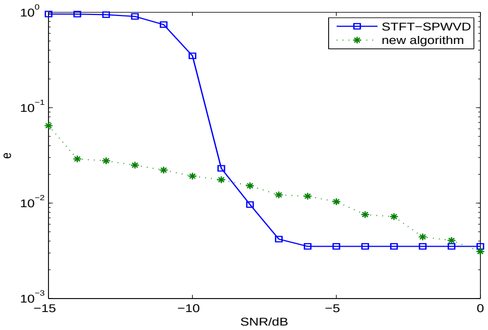

Fig. 2. Relative error curves of hop cycle estimation under different SNRs.

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