A Robust Detection Method of Frequency Hopping Signals

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Abstract: Under complicated high frequency (HF) environment, the SNR of frequency hopping (FH) signals is low, it is hard to detect FH signals. Constant False Alarm Rate (CFAR) is an effective detection of weak signals. First, one of CFAR methods called Cell Averagin Statistic Hofele (CASH)-CFAR was analyzed and modified to reduce calculations. In view of characteristics of FH signal, the modified CASH-CFAR was expanded to two dimension, then used this 2-D MCASH-CFAR at time-frequency spectrogram to pick out FH signals. Finally, morphological image processing was applied to the binary image after 2-D MCASH-CFAR in order to optimize the spectrogram. Simulations show that the long term signals can be eliminated while FH signals being detected, and the SNR of FH signals can heighten clearly which makes following processing more convenient.

Key words: frequency hopping signals; CASH-CFAR; signal detection; morphological image processing

1 Introduction

Signal detection is to filter the noise and detect the usful signal from received noiselized signals. Usually, we choose a characteristic function which is diffirent from noise and signals obviously, through a threshold to partition them. The pivotal problem is how to choose threshold. Actual high frequency (HF) channel brings selective fading and burst broadly interfere, they cause noise floor undulate obviously. Signal spectrogram leaking especially strong signal leaking can alter neighbor channels' noise floor, then use unitary threshold to detect weakly signal such as FH signal is difficult and won't accurate. Constant False Alarm Rate (CFAR) is one of the excellent detection for weakly signals, it is widely used in detection of radar signals[1]. Classical algorithm includes Cell Averaging (CA)-CFAR, Greatest Of (GO)-CFAR, Smallist Of (SO)-CFAR, and Order Statistic (OS)-CFAR etc. Based those methods, a new CFAR algorithm called Cell Averagin Statistic Hofele (CASH)-CFAR is designed in [2], its performance is more spreferably. We first modified the CASH-CFAR circuit in order to reduce calculations, then expanded that MCASH-CFAR to two dimension and use it at the time-frequency spectrogram to detect FH signals. That identification targets after 2-D MCASH-CFAR should filter by morphological image processing. The simulations show that using this method to detect FH signals is efficiency and roboust.

2 CASH-CFAR and Modified CASH-CFAR

2.1 Principle of CASH-CFAR

In [2], there was given a circuit of CASH-CFAR. It comprises a detecting unit by width of 1 storage cell and a shift register made of a sub-register, each containing L storage cells. Each sub-register has its own adder. Figure 1 shows the principle of the circuit.

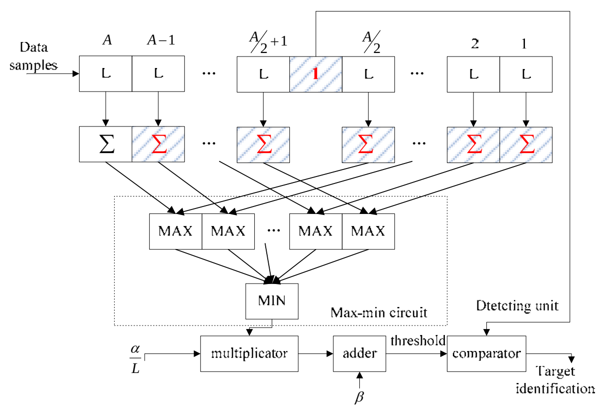

Figure 1: Principle of the CASH-CFAR circuit

By means of a special maximum-minimum process aclutter-representative sum-value, Sr, will be selected from the A sum-values, S1…SA. The threshold value is then calculated using a multiplicative (α/L) and/or additive (β) factor. Each sub-register has L storage cells, signals through each cell compare with the threshold, those who exceed are the identification targerts. That means each L samples must update the threshold once.

This circuit can preserve the signals larger than a, and wipe off the clutter waves less that b.

$$l_{signal} \le AL/2 - 2L + 2 = a \qquad (1)$$

$$l_{clutter} \ge AL/2 + L = b \qquad (2)$$

While each L samples update the threshold, it need $A \times (L-1)$ times addition operation everage.

2.2 Modified CASH-CFAR

In order to make calculation efficiently and make it convenient for expand, we modified that structure of CASH-CFAR to Figure 2, which we called MCASH-CFAR. The detecting unit enlarged to L storage cells, All sub-register adders changed to shift-registers expect the leftest-hand section. For this change, everage L samples need only $L-1$ addition operations and a shift operation. Operations reduce obviously.

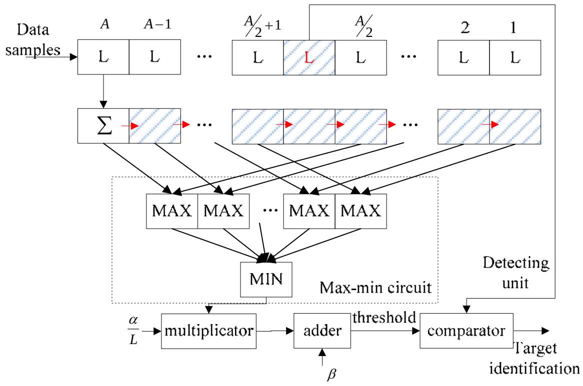

Figure 2. Principle of the modified CASH-CFAR circuit

This modified method could trace the change of noise floor in time, preserve the signals less than (or as wide as) $AL/2-L+1$, and wipe off the clutter waves larger that $AL/2+2L-1$. Concretely analysis is:

First supposed detecting signal is l_{signal} in width, restraining clutter waveform is $l_{clutter}$ in width, signal started at the ith register and lasted out $\Delta\,(1\le\Delta\le L)$ in that register.

If detecting sample is the useful reserved signal, based maximum-minimum principle, the maximum's minimum of the sum of every two registers must less than signal amplitude, so at least a pair registers $(k, A/2+k)$ $k=1,2,\cdots,A/2$ must be the noise. In order to fulfill this we must have the $(k, A/2+k)^{th}$ register of the (i -1)th sub-register don't cover any signal.

$$l_{signal} \le \left(A/2+i-2-(i+1)+1\right)L+L+\Delta = AL/2-L+\Delta \quad (3)$$

We wish all Δ could detect signal, it is requested

$$l_{signal} \le AL/2-L+1 \quad (4)$$

If detecting sample is the restraining clutter waveform, the maximum's minimum of the sum of every two registers must higher than (or as high as) signal amplitude, at least a pair registers $(k, A/2+k)$ $k=1,2,\cdots,A/2$ must be the noise. This includes two cases:

(a) When the length of clutter waveform in the ith sub-register last for $\Delta\,(1\le\Delta\le L-1)$, at least every two registers $(k, A/2+k)$ $k=1,2,\cdots,i$ required to store the clutter waveform. The length of clutter waveform equal to

$$l_{clutter} \ge \left[\left(A/2+i\right)-(i+1)+1\right]L+L+\Delta = AL/2+L+\Delta \quad (5)$$

(b) When the length of clutter waveform in the ith sub-register equealed to L, at least every two registers $(k, A/2+k)$ $k=1,2,\cdots,i-1$ required to store the clutter waveform. So the length of clutter waveform equal to

$$l_{clutter} \ge \left[\left(A/2+i-1\right)-i+1\right]L+L = AL/2+L \quad (6)$$

If we expect all $\Delta\,(1\le\Delta\le L)$ can restrain clutter waveform, it must satisfy:

$$l_{clutter} \ge AL/2+2L-1 \quad (7)$$

3 2-D MCASH-CFAR

3.1 Request of 2-D MCASH-CFAR

We always use time-frequency transform[3] to deal with FH signals. STFT is the most usful method. Suppose a discrete signal $x(n)$, it's STFT defines as:

$$STFT_x(n,k) = \sum_{m=-\infty}^{\infty} x(m)\gamma(n-m)e^{-j\frac{2\pi k}{N}m} \quad (8)$$

Figure 3 shows an actual signal received in HF channels. Figure 4 is time-frequency spectrogram of that actual signal. Degrees of grey indicate signal power intensity, the brighter the grey is the greater the signal power is.

From Figure 4 we can see that the intensity background noise is strong or weak variably, long term fixed frequency signals take up a majority frequency band and their powers are much stronger than the FH signals. It is difficult to choose

FH signals from such noise and interferes through a single threshold. If at any time we along frequency axis to detect FH signal by MCASH-CFAR or at any frequency we along time axis to detect FH signal, they both can only restrain the longer clutter waveform or interfere in a single direction, but we hope to detect them at both time and frequency axis. So expanding the MCASH-CFAR to 2-D is necessary.

3.2 Principle of 2-D MCASH-CFAR

Because frequency hopping signal is sensitive to the change of time, therefore along time axis we updated threshold every one signal sample, and along frequency axis we updated threshold every L_2 signal samples. According to this principle we designed the 2-D MCASH-CFAR circuit as

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Figure 5.

Detecting unit contained $1\times L_2$ storage cells, respectively corresponded to the amplitude of L_2 sequential cells in frequency axis at one time. Dot shadow in Figure 5 is the middle column of the detection unit, calculated the sum of the above and underside $A_1/2$ sub-registors of the detection unit respectively then got th_1 by the maximum-minimum principle. Catercorner shadow in Figure 5 is the row of the detection unit, calculated the sum of the left and right $A_2/2$ sub-registors of the detection unit respectively then got th_2 by the maximum-minimum principle also. Following, we made the maximum of th_1 and th_2 multiplied by α/L, The final threshold was the sum of the product and β. If the detecting unit was greater than the threshold, it was determined usful signal, otherwise was interfere. A_1 and L_1 should according to (1) and (2), A_2 and L_2 should according to (4) and (7).

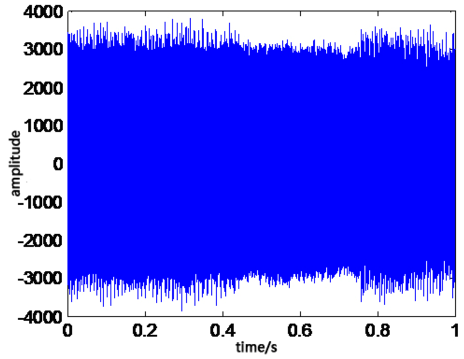

Figure 3. Waveform of an actual signal

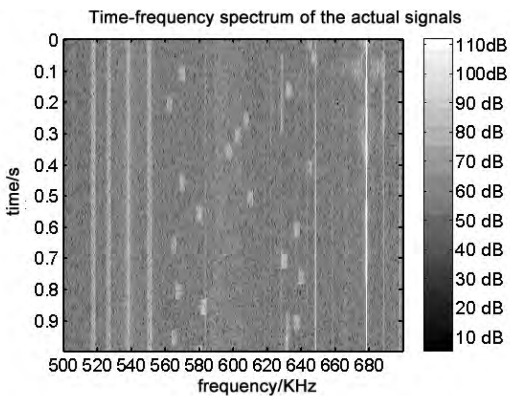

Figure 4. Time-frequency spectrogram of the actual signals

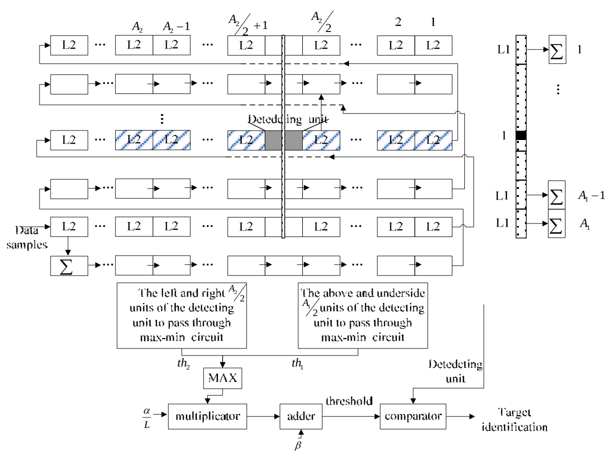

Figure 5. Principle of 2-D MCASH-CFAR circuit

4 Morphological Image Processing

Morphological image processing[5] aims at binary image. Its basic idea is using a specifically shape element to scale and pick-up the corresponding frame.

First dilate then erode called a close operation. Use element B to close A, denote $A\bullet B$, defines as

$$A\bullet B=(A\oplus B)\Theta B \tag{9}$$

First erode then dilate called an open operation. Use element B to open A, denote $A\circ B$, defines as

$$A\circ B=(A\Theta B)\oplus B \tag{10}$$

Close operation can fill small blank in the frame, connect adjacent closely frame and smoothing frame boundary. Open operation can eliminate small dot in the frame, separate two frame from a thin gap and smoothing bigger frame's boundary. They both don't change the area of the frame obviously.

We can look the spectrogram through 2-D MCASH-CFAR upon a binary image (signal is 1, interfere is 0). In order to smooth small blank space cause by virtual leak and eliminate noise dot cause by virtual alert, we adopt a 3×3 quadrate element to close detected spectrogram and open it following.

5 Simulations

As Figure 3 shows the actual received signal, Center frequency is 600KHz, bandwidth is 200KHz, sampling frequency is 2048KHz. First convey it to the zero intermediate frequency, then depress sampling frequency to 250KHz. Corresponding spectrogram shows in Figure 4.

The dashed in Figure 6 and Figure 7 are the threshold get from CASH-CFAR and MCASH-CFAR. We can see that they can both self-adaptively run after the change of noise floor. MCASH-CFAR reduced the addition operation from $A\times(L-1)$ to $L-1$ addition and A shift operation

Figure 8 is the estimation by 2-D MCASH-CFAR. We can see that 2-D MCASH-CFAR restrain long term signal and emerge sho rt time signal primely, the SNR of FH signal was heighten a lot. In Figure 8, there are much noise and much blank space at the signal frame.

Figure 9 shows the final spectrogram smooth by morphological image processing. We can see that all FH signal hops are preserved. At the same time most noise and interfere was removed. The blank was smooth away almostly. But there are some other modulate signal except FH signal. It must be apart by time-correlation[6] or bandwidth differ etc.

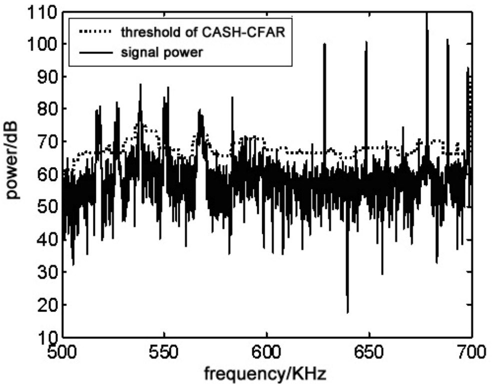

Figure 6. Threshold by CASH-CFAR

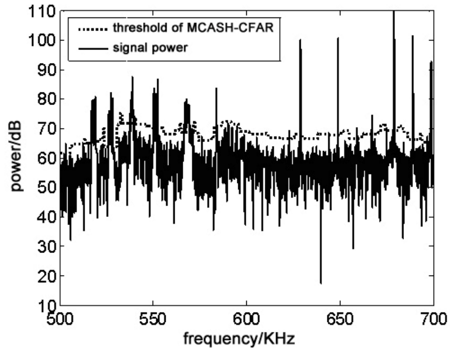

Figure 7. Threshold by modified CASH-CFAR

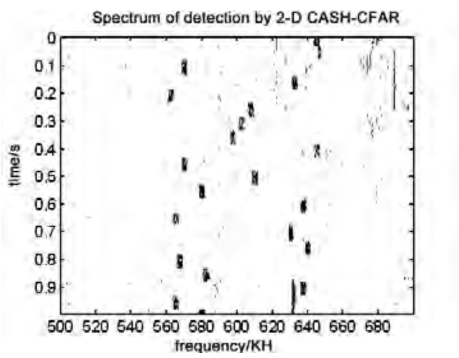

Figure 8: Identification of 2-D MCASH-CFAR

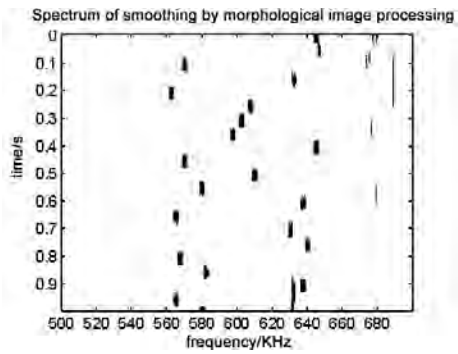

Figure 9. Identification of morphological processing

6 Conclusions

In the paper, we propose a new detection method of FH signals in HF channels. First we modified the CASH-CFAR circuit in order to reduce the additions, then expanded it to two dimension, and used it to detect FH signal at time-frequency spectrogram. Finally, we got the result by morphological image processing. This method can efficiently detect FH signal under complicated HF channels, at the same time the SNR of FH signal was heighten obviously. But the scheme has some limitations, such as 2-D MCASH-CFAR needs large numbers of registers, this make higher calculated complication.

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