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Detection of unknown FH signals using differential spectrum processing

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ABSTRACT
In this paper, a method for FH signal detection using differential spectrum processing in successive time periods. Proposed method has high detection probability in noise and interference. In case of several FH signals, time- frequency transfer of FH signals can be detected combining proposed method with direct finder (DF).

Keywords
spectrum differential processing, frequency hopping signal detection, FH communication

1. INTRODUCTION

FH communication has high anti-jamming capability to intent interference and third person cannot detect it. Without pre-knowledge, FH signals are difficult to detect. Energy-detection [4,5], spectrum analysis, energy-spectrum detection with scanner receiver and radar[3], spectrum processing[1 2] are used for FH signals detection.

In [3] a unknown FH signal detection method using scanner receiver and DF was proposed. Signals in certain band are split according to direction and FH signal is detected. This is not practicable in high speed of frequency hopping.

In [1] and [2], interference and noise spectrum is estimated and based on them scaled subtraction and division combination is used to estimate spectrum. But the interference and noise spectrum estimation takes a certain time period, in which interference changes. Then estimation accuracy decreases and thus spectrum estimation accuracy of FH signal also decreases

In this paper a method for detection of both of FH signal based on spectrum difference of 2 successive time periods and time-frequency transfer is proposed.

The rest of paper is organized as follows. Section II explains the proposed method, and section III shows a detection of multiple FH signals. Simulation results are provided in section IV and lastly section V provides conclusion.

2. Proposed Method

2.1 Detection of FH signal

FH signal may be detected as follows.

Received signal is divided into intervals of certain time period T_{con} and power spectrum is obtained in each period through DFT.

Obtaining the difference of DFT signals of successive time periods.

Considering the positive peak of the obtained “spectrum” (difference of DFT signal) as FH signal spectrum of i^{th} time period, and negative peak as FH signal spectrum of $(i+l)^{th}$ time period. (practically, certain threshold η is set)

In this method main parameters are T_{con}, number of DFT points, and threshold η.

Main point of the method is that frequency components of noise or interference in successive time periods are similar but FH signal is changed. We will call this method as Power Spectrum differential processing (PSDP).

FH signal uses FH series whose period is longer than communication time and in a hopping period frequency don't overlap, so that we may assume that in $2^{T_{con}}$ frequencies in FH signal don't overlap.

Received signal x(n) can be modeled as follows.

$$x(n) = r_{FH}(n) + r_I(n) + \sum_{l=1}^{M} r_{CW,l}(n) + N(n) \quad (1)$$

where $r_{FH}(n)$ is FH signal, $r_I(n)$ impulsive interference signal, $r_{CW,l}(n)$ l^{th} narrowband signal when considering continuous interference signal as sum of M narrowband signals and $N(n)$ additive Gaussian noise.

N points DFT of $x(n)$ is

$$X(k) = \sum_{n=0}^{N-1} x(n)e^{-j2\pi nk/N}, k = \overline{0, N-1} \quad (2)$$

Xi(k) is X(k) in i^{th} period, $|X_i(k)^2| = y_i(k),\ k = \overline{0, N-1}$ and

$$y_i \overset{\Delta}{=} (y_i(0), y_i(1), \cdots, y_i(N-1)) \quad (3)$$

If we assume that noise, interference and FH signal are independent in (3), then

$$y_i(k) = A_{FH,i}(k) + A_{I,i}(k) + \sum_{l=1}^{M} A_{CW,i,l}(k) + A_{N,i}(k) \quad (4)$$

where $A_{FH,i}(k)$, $A_{I,i}(k)$, $A_{CW,l,i}(k)$, $A_{N,i}(k)$ are kth components of power spectrum of l^{th} period of $r_{FH}(n)$, $r_I(n)$, $r_{CW}(n)$, $N(n)$.

Repeating above steps in $(i+l)^{th}$ period, then

$$y_{i+1} = (y_{i+1}(0), y_{i+1}(1), \cdots, y_{i+1}(N-1)) \quad (5)$$

$$y_{i+1}(k) = A_{FH,i+1}(k) + A_{I,i+1}(k) + \sum_{l=1}^{M} A_{CW,i+1,l}(k) + A_{N,i+1}(k) \quad (6)$$

If there is no occurrence or destruction of interference, spectra of noise and interference are same and frequency of FH signal is different, then following expressions hold.

$$\begin{cases} A_{FH,i}(k) \neq A_{FH,i+1}(k) \\ A_{I,i}(k) = A_{I,i+1}(k) \\ A_{CW,i,l}(k) = A_{CW,i+1,l}(k) \\ A_{N,i}(k) = A_{N,i+1}(k) \end{cases} \quad (7)$$

Therefore, difference "spectrum" of i^{th} and $(i+l)^{th}$ periods is

$$y_{i,i+1} \overset{\Delta}{=} y_i - y_{i+1} = (y_i(0) - y_{i+1}(0), \cdots, y_i(N-1) - y_{i+1}(N-1))$$

$$= (A_{FH,i}(0) - A_{FH,i+1}(0), \cdots, A_{FH,i}(N-1) - A_{FH,i+1}(N-1)) \quad (8)$$

From (7) and characteristics of FH signal, either $A_{FH,i}(k)$ or $A_{FH,i+1}(k)$ has value, i.e., at least either of them is 0. Consequently

$$y_{i,i+1}(k) = y_i(k) - y_{i+1}(k) = \begin{cases} 0 & \text{;no FH signal on } k^{th} \text{ frequency point} \\ A_{FH,i}(k) & \text{;FH signal in } i^{th} \text{ period on } k^{th} \text{ frequency point} \\ -A_{FH,i+1}(k) & \text{;FH signal } i+1^{th} \text{ period on } k^{th} \text{ frequency point} \end{cases} \quad (9)$$

As can be seen from (9) FH signal spectrum of i^{th} period is positive and $(i+l)^{th}$ period is negative.

2.2 Detection of time-frequency transfer

Complete detection of FH signal includes not only fining of FH signal but also detection of time-frequency transfer of FH signal. d

Time-frequency transfer may be detected as follows.

If M FH signal spectra are found in observed period $[kT_{con}, (k+1)T_{con}]$, the period is divided into M sub-periods.

In each sub-period, repeat the PSDP.

Arrange the frequencies corresponding to detected peak values in sub-periods in time, we can get time-frequency transfer.

3. Detection in several FH signals

If there exist several FH signals following processing should be performed.

In this case DF is essential. Without loss of generality, assume that M FH signal spectra are detected in $[kT_{con}, (k+1)T_{con}]$. Then, first, feed the information of M FH signals into DF and decide direction of each signal. In each direction number of peaks of frequency is M, which is appropriately large and not 1 or 2, so in frequency histogram the direction with M=1 (or no much larger than 1) may be ignored. Such signal may be considered as narrowband signal. (under the condition of appropriate hopping speed).

If in direction θi, there are M1 spectra, and in θ2, M2 spectra,..., in θl, Ml spectra, then in received signal there exists L FH signals with hopping speed of $\frac{T_{con}}{M_i}$ $(i = \overline{1, l})$

And then either of following methods (A or B) is used to detect time-frequency transfer.

A) Split the received signal in direction θi into $\frac{T_{con}}{M_i}$ intervals and if there is 1 FH signal, obtain the time-frequency table with steps ⓐ~ⓓ.

B) Split All the received signals in $[0, T_{con}]$ into $M_k = \max(M_i)$ $(i = \overline{1, l})$ intervals. Apply PDSP to get time series of M frequencies. Divide the obtained time series with directions θ_i $(i = \overline{1, l})$ based on directional frequency list.

A is simple but hardware-demanding and B is complicated in algorithm but not hardware-demanding. B is applicable only when frequency collision probability (quantized with Hamming correlation) is low.

Detection algorithm of FH signal mentioned above is summarized as follows.

Filter the received signal by filter with passband which is optimal or suboptimal for FH communication.

Perform PSDP on received signal in period of 2Tcon in which probability of occurrence or destruction of interference is negligible (but there may be several hoppings).

If there exist Ml peaks in obtained "spectrum", which can be seen as FH signal, recognize as detection of FH signal and with DF divide the M signals in l directions.

Using A or B, obtain time-frequency transfer table.

4. Simulation Result

Block diagram of proposed detection algorithm is as follows.

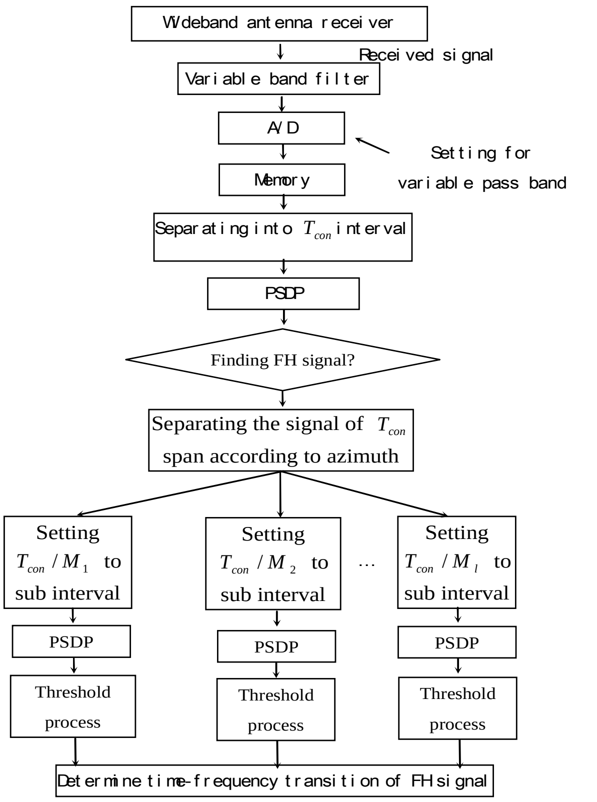


Figure1. Detection Block Diagram of FH signal using PSDP

We simulate the proposed method with Matlab Simulink

Simulation environment is as follows: SNR=-10~-25dB ,SIR=-20dB, frequency hopping speed 2000/s ~5000/s, $T_{con} = 2ms$,frequency of occurrence or destruction of interference $10^4 \sim 10^6$ /day ,duration of interference T_i is random, number of points of FFT 4096,16384. Frequency band of FH signal is 3~30MHz, FH series is PN sequency of period 212-1. Frequency band of interference signal is also 3~30MHz, and the number of interference signals are in 20~1000.

Spectra of received signals in 2 time periods are shown in figure 2. (SIR=-20dB,SNR=-20dB)

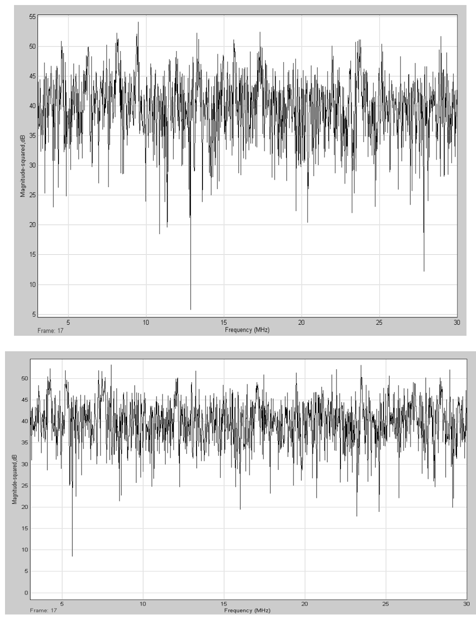
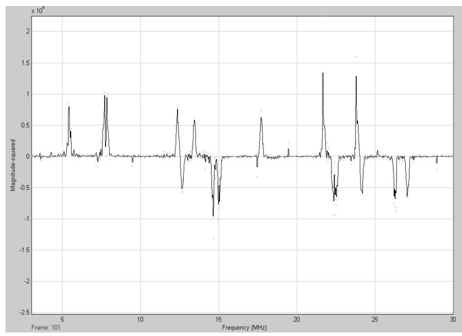
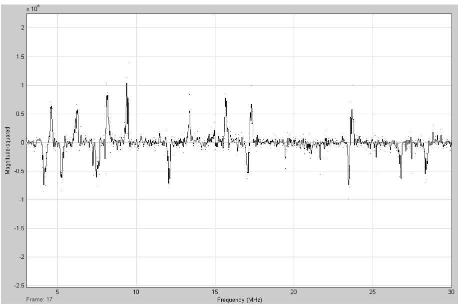


Figure 2. Spectrum of received signal in 2 time periods

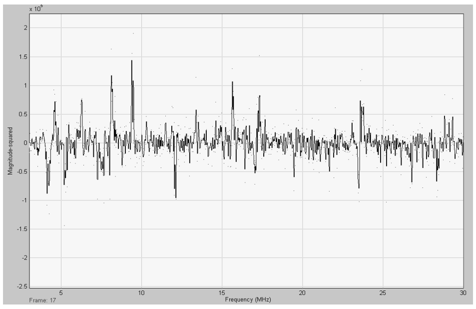
As can be seen from the figure, before PSDP spectrum of FH signal is embedded in interference and noise. Resultant spectrum after PSDP is shown in figure 3.



SNR=-10dB, SIR=-20dB



ㄴ) SNR=-20dB, SIR=-20dB



ㄷ) SNR=-25dB, SIR=-25dB

Figure3. "Spectrum" detected in different SIR, SNR

As can be seen, detection of FH signal at SNR=-25dB and SIR=-25dB is possible.

Following tables show performance comparison of proposed and previous [1] methods.

Table 1. Comparison of previous (quotient combining) and proposed method (Number of detected hopping in case there are 6 hopping in a frame)

SNR (dB) / SIR (dB)	0	-3	-6	-9	-12	-15	-20	-25
0	6/6	6/6	6/6	6/6	5/6	5/6	5/6	4/6
-3	6/6	6/6	6/6	6/6	4/6	4/6	3/6	2/6
-6	6/6	6/6	6/6	5/6	4/6	3/6	2/6	1/6
-9	6/6	6/6	5/6	5/6	3/6	2/6	1/6	0/6
-12	4/6	4/6	4/6	4/6	2/6	1/6	0/6	0/6
-15	3/6	3/6	2/6	2/6	1/6	0/6	0/6	0/6
-18	1/6	1/6	0/6	0/6	0/6	0/6	0/6	0/6
-20	0/6	0/6	0/6	0/6	0/6	0/6	0/6	0/6
-25	0/6	0/6	0/6	0/6	0/6	0/6	0/6	0/6

Table 2. Comparison of previous(scaled subtraction combining) and proposed method (Number of detected hoppings in case there are 7 hoppings in a frame)

SNR (dB) / SIR (dB)	0	-3	-6	-9	-12	-15	-20	-25
0	7/7	7/7	7/7	7/7	2/7	0/7	0/7	0/7
-3	7/7	7/7	7/7	7/7	2/7	0/7	0/7	0/7
-6	7/7	7/7	5/7	3/7	1/7	0/7	0/7	0/7
-9	5/7	4/7	3/7	2/7	0/7	0/7	0/7	0/7
-12	2/7	1/7	1/7	1/7	0/7	0/7	0/7	0/7
-15	0/7	0/7	0/7	0/7	0/7	0/7	0/7	0/7
-18	0/7	0/7	0/7	0/7	0/7	0/7	0/7	0/7
-20	0/7	0/7	0/7	0/7	0/7	0/7	0/7	0/7
-25	0/7	0/7	0/7	0/7	0/7	0/7	0/7	0/7

5. Conclusion

In this paper a detection method of unknown FH signal using spectrum difference in successive time intervals is proposed. Proposed method shows better performance compared with previous methods.

Simulation results show that proposed method is valid and robust to occurrence and destruction of interference signal.

6. REFERENCES

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