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Research on Follower jamming of FH Communication

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Abstract. In this paper, Firstly, the follower jamming and the jamming ellipse are introduced; After studying the jamming ellipse and combining the mathematical model of FH signal, the mathematical model of follower jamming is built; the performance of FH communication under the follower jamming is analyzed; Finally, the anti-jamming measures of follower jamming are proposed，In the future research, these can supply the foundation for the feature extraction of the follower jamming identification.

Keywords: component, follower jamming, jamming ellipse, MFSK, bit error rate, anti-follower jamming

1. Introduction

Frequency-hopped spread-spectrun(FHSS) systems are used extensively in military communications to neutralize the effects of various types of intentional jamming, which contain follower jamming and barrage jamming[1]. FH communication can be efficiently jammed by the follower jamming. In follower jamming, the jammer intercepts the transmittter signal, tries to determine the frequency of the hop, and then generates jamming in a narrow range about this frequency. Now It is reported that the ferret receiver has been appeared which can invigilate 80 channel at the same time and the scaning speed is 80,000 channles 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[2].

It is well known the geometrical restriction of follower jamming, Basis of the characteristic of follower jamming and the mathematical model of FH signal. The mathematical model of follower jamming can be built, bit error rate of FH communication system under the follower jamming are studied. In the future research, these can supply the foundation for the feature extraction of the follower jamming identification.

The structure of this paper is arranged as follows. Firstly, the conception and the characteristic of follower jamming are introduced, and then the geometrical configu-ration of communicators and jammer are described, which can be called the jamming ellipse, the mathematical model of follower jamming is built, the performance of FH communication under the follower jamming is analyzed , At the end, some anti-jamming of follower jamming are proposed.

2. Follower Jamming and Jamming Ellipse

2.1. Follower jamming in the FH

Follower jamming is a jamming means which the jamming signal can track the frequency hoping , the instantaneous frequency of jamming signal is narrower,but Its can overlap the instantaneous frequency of every frequency . The follower jamming is a correlate jamming of some condition that the jamming enegy must reach the victim receiver before it hops to a new set of frequency channels, Thus ,the greater the hopping rate,the more proteted the frequency hopping system is against a follower jamming.The jamming

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waveform is usually a noise-modulated signal that can perhaps be modeled as a stationary Gaussian process with a narrowband power spectrum or tone-modulated.

The characteristic of carrier jamming signals of follower jamming are too dimilar to the desired signal. Figure 1 and Figure 2 show the conceptual diagrams of the FH signal and and the follower jamming, respectively, on a time-frequency domain, where x-axis and y-axis represent the time domain and the frequency domain, the figure 1 shows the FH signal without the follower jamming , and the figure 2 shows the conceptual diagram of follower jamming. As shown in Figure 2, in order to jam the FH signal, it is essential to re-track the hopped signal frequency within the hop duration for each hop. In other words, in case of follower jamming, it is required for the follower jammer to find the hopped frequency at first, and then the jammers noise signal is transmitted during the remaining time of the hop[3].

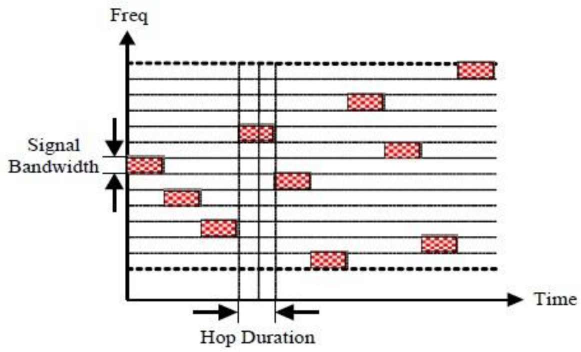

Figure 1 Conceptual Diagram of FH Communication

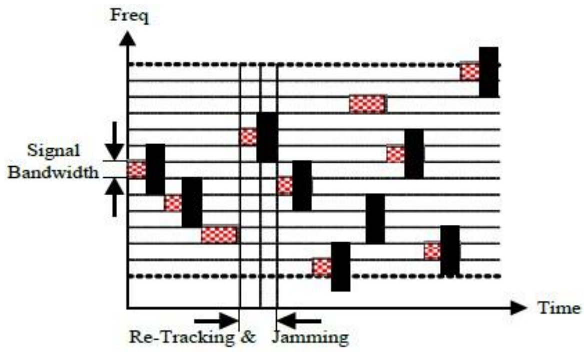

Figure 2 Conceptual Diagram of Follwer jamming

2.2. Jamming Ellipse

In the research of the follower jamming, because of the limitation of distance and speed ,the follower jamming can take the effect only in the fixed region[4-6]. Figure 3 depicts the geometrical configuration of communicators and a jammer . For the follower jamming to be efffective,

We must have

$$\frac{d_2+d_3}{v}+T_j \le \frac{d_1}{v}+\eta T_h \tag{1}$$

Where v is the speed of an electromagnetic wave, *d1* is the distance of transmitter to receiver, *d2* is the distance of transmitter to jammer, *d3* is the distance of Jammer to receiver, *Tj* is the processing time required by the jammer, η is a fraction, and T_h is the hop duration. This inequaluty states that the arrival-time delay of the jamming relative to the desired signal at the receiver must not exceed a certain fraction of the hop duration if the jamming is to be effective, The value of η is determined by the jamming power at the receiver and the details of receive design etc.

A rearrangement of (1) yields

$$d_2+d_3 \le (\eta T - Tj)v + d_1 \tag{2}$$

The right-hand side of this inequality can be regarded as a constant, then the formula(2) can defines an ellipse with the transmitter and the receiver at the two focal, If the follower jammer is outside this ellipse, the jamming can not be effective.

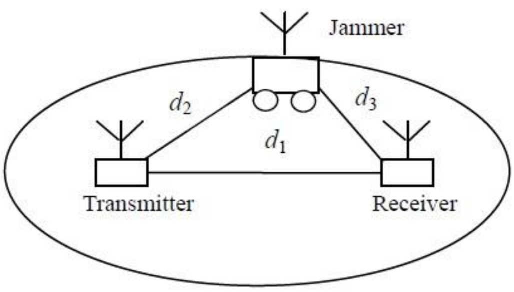

Figure 3 Sketch of jamming ellipse

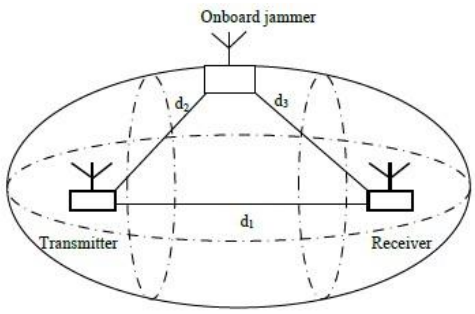

Figure 4 Sketch of jamming ellipsoid in the airspace

Sometimes, the jammer will be in the airspace, and also the jamming ellipse can be expanded to the jamming ellipsoid. just as the Figure 4 shows, and If the follower jamming wants to be effective ,the Onboard jamming should be in the ellipsoid .

2.3. Mathematical Model of Follower Jamming

After studying the jamming ellipse and combining the mathematical model of FH signal , The formula of follower jamming can be gone out in the derivation. The mathmatic formula of the single frequency hopping signal is[7].

$$S_{\mathrm{i}}(t) = A_h m_i(t)\cos(w_i t + \phi_i) \tag{3}$$

Where $m_i(t)$ is the Modulation signal , A_h is the signal amplitude, w_i and ϕ_i are respectively define the frequency and phase of the FH signal in the slot time j . and if the T_h is the hop duration, we can get that $jT_h \le t \le (j+1)T_h$.

Because the signal characteristic of follower jamming is similar with the FH signal, the difference of them are modulation signal and delay time. Before the upper we kown If the follower jamming can be effective, the jammer should not outside the ellipse and according to this ,the delay time follower jamming can be defined as follows

$$S_j(t) = A_j m_j(t)\cos(w_j(t-\Delta t) + \phi_j) \tag{4}$$

Where A_j is the amplitude follower jamming, $m_j(t)$ is the modulation signal of jamming, Its can be the noise or tone. w_j is the frequency of FH signal which is intercepted and tracked by the jammer. ϕ_j is the phase of the jamming signal.

Δt is the delay time which is contained with two parts, One part is the reaction time of jammer which is included with intercept and transmitting, The other part is the differ distance from the transmitter to receiver and the sum of transmitter to jammer with jammer to receiver, the formula as the following.

$$\Delta t = \frac{d_1 + d_2 - d_3}{v} + Tj \tag{5}$$

This formula is founded just when the $\Delta t < T_d$,where T_d is the dwell time of FH signal.when we know the matamatic modal of FH signal and follower jamming ,Its can supply the foundation for the feature extraction of the follower jamming identification. In the next section, the performance of FH communcation in the follower jamming will be proposed.

3. Bit Error probability of The Folloer Jamming

In order to research the performance of FH communica-tion under the follower jamming, we will assume the modulation method of the FH communication system is MFSK, and then we will give the bit error rate in the MFSK without follower jamming and in the follower jamming.

The bit error rate of an uncoded system in the AWGN-channel is[8].

$$P_{\mathrm{b}} = (\frac{2^{k-1}}{2^k - 1})\sum_{n=1}^{M}(-1)^{n+1}\binom{M-1}{n}\frac{1}{n+1}\exp(-\frac{-nkE_b}{(n+1)N_0}) \tag{6}$$

Where E_b is the energy per bit , N_0 is the one-sided power spectral density of noise and $M = 2^k (k = 1,2,3\cdots)$ is the number of symbols where k is the number of bits per symbol.

$$\binom{M-1}{n} = \frac{(M-1)!}{n!(M-1-n)!} \tag{7}$$

In the follower jamming , There are two modulation signal, One is the noise, the other is the tone, Next, we will introduction the bit error rate of MFSK modulation which are jammed by the follower jamming signal of noise and tone respectively.

Firstly, the calculation formula of bit error rate in the follower noise jamming are as follows[9].

$$P_{\mathrm{b}}=(\frac{M}{2(M-1)})\sum_{n=1}^{M-1}(-1)^{n+1}\binom{M-1}{n}\frac{\frac{1}{n+1}}{1+\frac{E_b/N_0}{E_b/N_J}}\exp(-\frac{kE_b/N_J}{1+\frac{E_b/N_0}{E_b/N_J}(\frac{n+1}{n})}) \tag{8}$$

Where E_b/N_0 is the signal bit energy-to-ambient noise density ratio and E_b/N_J the signal bit energy-to-jam noise density ratio in the followed channel.

Then, the calculation formula of bit error rate in the follower tone jamming are as follows.

$$P_{\mathrm{b}}=(\frac{M}{2(M-1)})\sum_{n=1}^{M-1}(-1)^{n+1}\binom{M-1}{n}\frac{1}{n+1}\exp(-\left[k\frac{E_b}{N_0}(1+R)\frac{n}{n+1}\right].I_0[\frac{2n}{n+1}k\frac{E_b}{N_0}\sqrt{R}] \tag{9}$$

$$R=\frac{E_J}{kE_b}=\frac{E_J}{E_S}=\frac{P_J}{P_S} \tag{10}$$

Where P_J is the power of signal , and the P_S is the power of the jamming signal.

4. Rerults and Simulation

In order to verify the performance of MFSK in the follower jamming, Firstly we analysis the performance of the MFSK/FH system which are jammed by the follower noise jamming , Assuming the M=4, In the Figure 5, when the FH system are without the follower noise jamming and E_b/N_J = -5dB, 5dB, 10dB respectively, the bit error rate curve diagram has been plotted. From the curve it can be seen that as the noise jamming power increases so dose the probability of bit error . For example, when the pb=10-e4, the difference of E_b/N_0 between no follower jamming and $E_b/N_J=10$ is the 4 dB, but when the $E_b/N_J=5$ and $E_b/N_J=10$ is up to the 12 dB. In the Figure 6 , the bit error rate curve diagram are plotted , when the M=2, 4 and 8 respectively.From the curve it can be seen that with the M curve increasing, if the system wants to achieve the same peformance, the E_b/N_0 has been reduced. Thus , in the real application, the anti-jamming peformance is raising when the M is raising.

When we analysis the peformance under the follower tone jamming , we can get the same conclusion. The result of the bit error rate curve diagram shows as the Figure 7 and Figure 8 is.

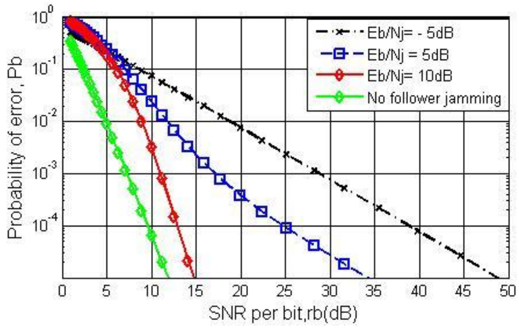

Figure 5 4FSK/FH Performance Against Follower noise jamming

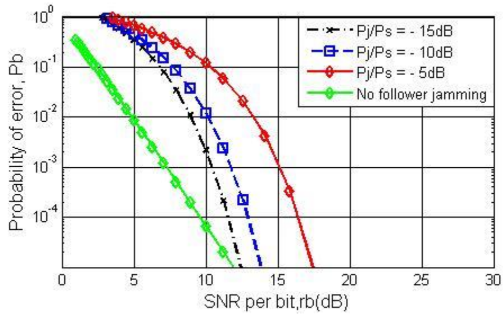

Figure 7 4FSK/FH Performance Against Follower tone jamming

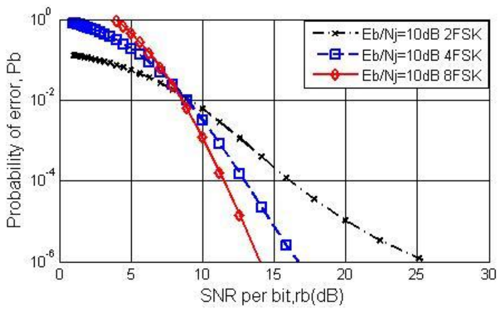

Figure 6 MFSK/FH Performance Against Follower noise jamming

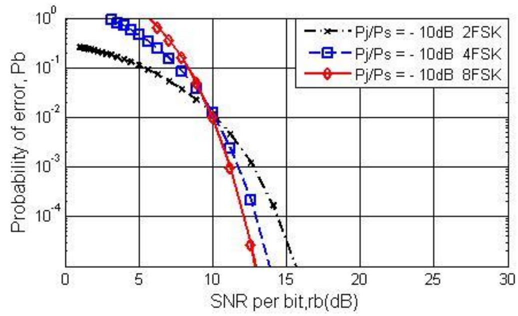

Figure 8 MFSK/FH Performance Against Follower tone jamming

5. The Anti-jamming Measure

According to the character of follower jamming and the restricion of the jamming ellipse,some anti-jamming of follower jamming can be proposed[4][10].

5.1. Raising the frequency hopping speed

The higher speed of FH communication, the stronger ability that against to the follower jamming. When the FH speed is raised , the dwell time of FH signal is reduced, in the formula (5) we know that the Tj will be reduced, which need very high performance of jammer .

5.2. Changing the frequency hopping speed

The higher speed of FH communication, The higher synchro of it, and the spruious signal may be arised by the high hop speed. Also the Frequency range bandwidth and equipment cost should be considered, so changing the FH speed is become the trend to against the follower jamming of every country. The jamming strategy can be broken by changing the FH speed or the dwell time of FH fake randomly, even changing nonlinearity.which made the interceptor can only scan the FH signal without the time orderly , and the difficult of folllower jamming is increased.

5.3. Using the jamming ellipse

From the formula of the jamming ellipse. It is decided by the dwell time of FH signal, reaction time of jamme , the distance and location of antenna between transmitter and receiver,If the follower jamming can be effective. By way of the analysis to the jamming ellipse, the anti-jamming measures to follower jamming are followed.

(a) Increasing the the system reaction time of jammer, FH networking communication can increase the identifi-cation difficulty of jammer, Its makes the processing time long.

(b) Reducing the dwell time in the airspace.

(c) Avoiding the jammer fall into the jamming ellipse , In the tactical communication, Its can be effective to reduce the probability of FH communicaton that abridge the range of jamming ellipse. In the real communicaton, we can reduce the distance of transmitter and receiver.

6. Conclusion

In this paper, Firstly the follwer jamming and the jamming ellipse are the introduced. After studying the jamming ellipse and combining the mathematical model of FH signal, the mathematical model of follower jamming is built ,also the performance of FH communication under the follower jamming is analyzed. In the future research, these can supply the foundation for the feature extraction of the follower jamming identification.

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