RESEARCH ON EVALUATION ALGORITHM OF COMMUNICATION JAMMING EFFECT BASED ON TOPSIS

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At present, the research on evaluation of communication jamming effect is still in its infancy. Aiming at the limitations of evaluation index selection and the complexity of evaluation of communication jamming effect, this paper proposes a comprehensive evaluation method based on Technique for Order Preference by Similarity to an Ideal Solution algorithm. Firstly, the evaluation index system of jamming effect is established by analyzing the jamming signals. Secondly, the subject-objective weighting method is used to highlight the influence degree of each index on the jamming effect evaluation system in the form of weight. Then, data preprocessing method and TOPSIS algorithm are described. Finally, the evaluation method of the jamming effect based on TOPSIS is proposed, and the simulation implementation of the evaluation algorithm is made, and the comparison with the evaluation method of the jamming effect based on the grey relational degree is made, and verified the rationality and feasibility of the evaluation method.

Key Words : *Characteristics of jamming signals, Technique for Order Preference by Similarity to an Ideal Solution, Jamming effectiveness evaluation, Constructing evaluation index system*

1. INTRODUCTION

The typical ECM system mainly consists of four modules: reconnaissance, evaluation, decision and jamming. Jamming effect evaluation can be carried out before jamming implementation to realize the optimization of jamming strategy. After that, it can provide data support for the next jamming. Therefore, the research of jamming effect evaluation technology has very important military application value[1)].

In the evaluation of jamming effect based on radar, some performance parameters are usually selected as evaluation indexes[2)]. Reference 3 choose the degree of performance loss to evaluate radar jamming scheme.

Research on the evaluation of communication jamming effect is in its infancy. Reference 4 improved the mean square error formula to evaluate the effect of single-tone jamming on FM signals.

Reference 5 proposed a comprehensive evaluation method based on Grey relational analysis method, and only considered the weight of indicators in this paper.

This paper proposed a evaluation method for communication jamming systems. Firstly, Traditional evaluation model is not considered the completeness and consistency when selecting jamming indicators. Based on the analysis of the jamming signal, the jamming effect evaluation index system is established; Secondly, Traditional weighting algorithms can not consider subjectivity and objectivity at the same time. In order to evaluate the prior knowledge and not lose objectivity in the final result, the indicators are weighted by subject-objective weighting method in this paper; Thirdly, Because grey correlation analysis is too subjective and difficult to determine the optimal value of some indicators. TOPSIS algorithm has no strict requirements on data distribution, number of indicators and sample size[6]. It can realize the maximum utilization of original data information, and its results can more accurately reflect the differences of various strategies. This paper completed the improvement of the TOPSIS algorithm by selecting and designing the optimal ideal solution; Finally, this paper uses the jamming index after weight design to evaluated the jamming effect, and completed the simulation comparison with the communication jamming effect based on gray correlation analysis, then, given the simulation results and conclusions.

2. JAMMING EFFECT EVALUATION MODEL

The three core contents of communication jamming effect evaluation are evaluation criterion, evaluation index and evaluation method[7-8]. Evaluation criterion is the main basis of jamming evaluation; evaluation index is the key basis of jamming evaluation; evaluation method is the mathematical way of quantitative analysis of jamming effect under evaluation index. Steps of jamming effect evaluation:

Step 1: Determine the jamming effect evaluation criteria according to the interfered party's strategy and the jamming status of the interfered party.

Step 2: According to the selected evaluation criteria, establishing evaluation index system.

Step 3: Selecting appropriate evaluation methods according to the evaluation system.

In this paper, the construction principles of communication jamming effect evaluation index system are summarized as simplicity, objectivity, testability, completeness, independence and timeliness. Because the weight of each index in the index system will affect the final evaluation result, in order to evaluate the prior knowledge and not lose the objectivity of the final result, this paper uses the subject-objective weighting method to design the weight. The subjective weight is obtained by AHP[9], and the objective weight is obtained by entropy method.

There are two kinds of subject-objective weighting methods:

$$\omega_i = \frac{a_i b_i}{\sum_{i=1}^{m} a_i b_i} \quad (1)$$

$$\omega_i = \alpha a_i + (1-\alpha) b_i, (0 \le \alpha \le 1) \quad (2)$$

Equation 1 is multiplication integration method, equation 2 is additive integration method. Where ω_i is the comprehensive weight of the i-th index, a_i , b_i are subjective weight and objective weight respectively. α is the weighting factor.

Because the weight distribution of the indicators in this paper is relatively uniform, this paper uses the multiplication integration method for subjective and objective weighting. This paper proposed jamming effect evaluation algorithm based on TOPSIS algorithm, and compares it with an evaluation algorithm based on gray correlation analysis.

3. EVALUATION INDEX SYSTEM

(1) Analysing of jamming signal

In this paper, the center frequency of jamming signal is 20 MHz, the baseband noise bandwidth is 10 MHz, and the sampling frequency is 80 MHz. Next, simulated and analyzed the jamming signal based on the above conditions.

Noise amplitude modulation jamming signal:

$$J(t) = \left[U_0 + U_n(t)\right]\cos\left(\omega_j t + \varphi\right) \quad (3)$$

where U_0 is the carrier amplitude, $U_n(t)$ is the modulated noise, φ is the initial angular phase, and ω_j is the carrier center frequency.

Assuming that the bandwidth of the jamming signal is 20 MHz and the power of the jamming signal is 10 W. The simulated noise amplitude modulation signal is shown in **Fig.1** and **Fig.2**. **Fig.2** shows that the modulated power spectrum consists of carrier spectrum and symmetric side lobe spectrum, the power is mainly distributed in the frequency band of width 20 MHz centered on 20 MHz.

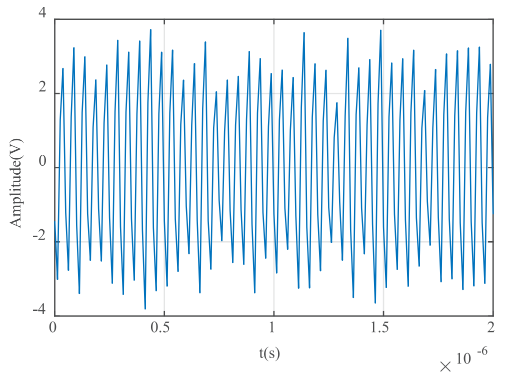

Fig.1 Noise amplitude modulation signal.

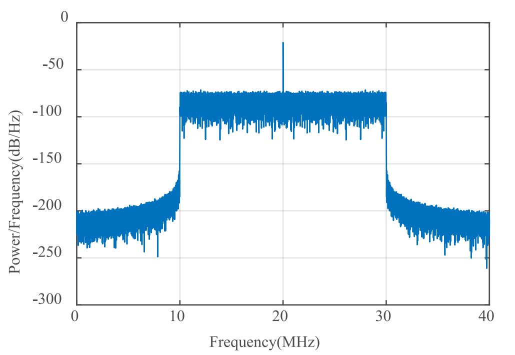

Fig.2 Noise amplitude modulation power spectrum.

The mathematical expression of noise FM jamming signal can be expressed as:

$$J(t)=U_j\cos\left[\omega_j t+2\pi K_{FM}\int_0^t u\left(t'\right)dt'+\varphi_0\right] \quad (4)$$

where $u(t)$ is the modulation noise, φ_0 is the initial phase, U_j is the signal amplitude, and K_{FM} is the frequency modulation slope.

Assuming that the FM index is 1 MHz. The simulated noise FM signal is shown in **Fig.3** and **Fig.4**.

Fig.4 shows that the power spectrum energy of the noise FM signal is relatively concentrated. And the signal bandwidth can be changed by the frequency modulation coefficient and noise power.

Sawtooth sweep jamming is a wideband jamming signal and time-sharing in both frequency domain and time domain. The mathematical model of frequency sweeping jamming is shown as follows.

$$J(t)=U_j X(t)\cos\left(2\pi f_j t+\theta_t+\varphi\right) \quad (5)$$

where $X(t)$ is RF noise jamming, U_j is the amplitude of the sweeping jamming signal, φ represents the initial phase of the jamming signal, and f_j is the instantaneous frequency.

Assuming that the sweep noise bandwidth is 10 MHz, the sweep frequency width is 20 MHz (the sweep frequency range is 10 MHz~30 MHz), and the sweep frequency slope is 10 kHz/us. The simulation sawtooth wave sweep frequency jamming signal is shown in **Fig.5** and **Fig.6**. We can be seen from the simulation results that it is consistent with the simulation data.

(2) Communication jamming index

a) Power suppression index E1

The jamming signal ratio when communication is interfered should be greater than the jamming signal ratio during normal communication[10].

$$E_1=\begin{cases}0, p_j/p_s\leqslant 0.5k_i\\ \dfrac{2}{3}\cdot\dfrac{p_j/p_s}{k_i}-\dfrac{1}{3}, 0.5k_i<p_j/p_s<2k_i\\ 1, p_j/p_s\geqslant 2k_i\end{cases} \quad (6)$$

where p_j is jamming power received by jammer, p_s is useful signal power received by the interfered party, and k_i is the threshold of dry signal ratio required by the interfered party for normal operation, and taken as 2 in this paper.

b) Frequency domain overlap index E2

The degree of overlap in frequency between the jamming signal and the communication signal should be the greater the better[10].

$$E_2=\begin{cases}0, f_3>f_2\\ \dfrac{\min(f_4,f_2)-\max(f_1,f_3)}{f_2-f_1}, f_3<f_2, f_4>f_1\\ 0, f_4<f_1\end{cases} \quad (7)$$

where $f_1\sim f_2$ is the frequency band range of the receiver, and $f_3\sim f_4$ is the frequency band range of the jammer.

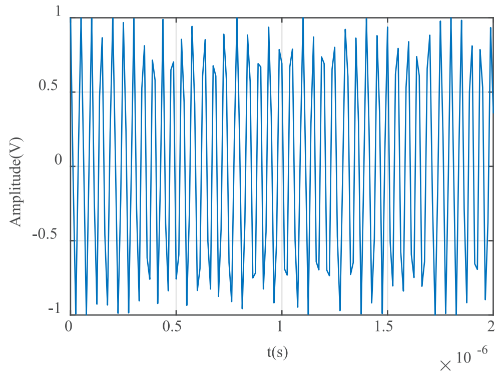

Fig.3 Noise FM signal.

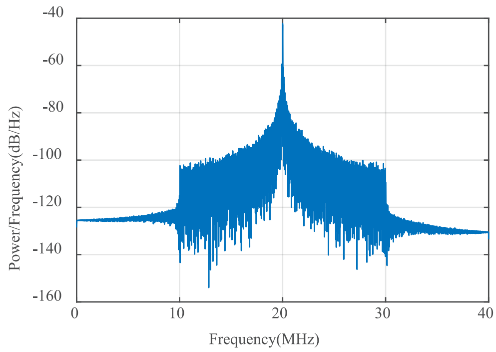

Fig.4 Noise FM power spectrum.

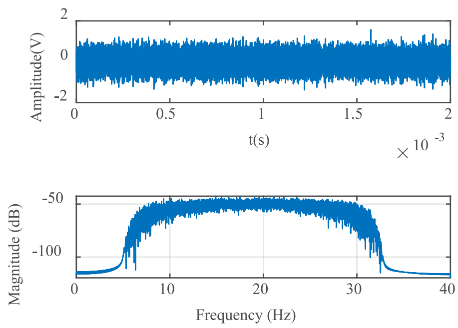

Fig.5 Sawtooth wave sweep signal and power spectrum.

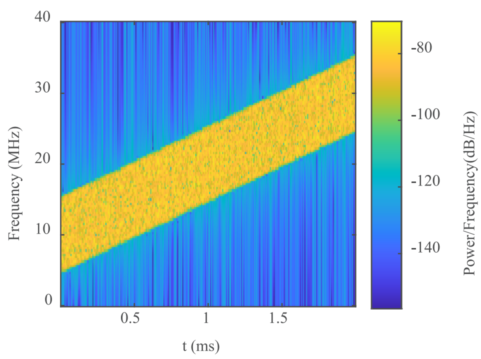

Fig.6 Time-frequency of sawtooth wave sweep signal.

c) Time domain overlap index E3

The ratio of jamming suppression time and threat time should be as large as possible. Set the threat time as $t_1 \sim t_2$ and the effective jamming time as $t_3 \sim t_4$ [10].

$$E_3 = \begin{cases} 0, t_3 > t_2 \\ \dfrac{\min(t_4, t_2) - \max(t_1, t_3)}{t_2 - t_1}, t_3 < t_2, t_4 > t_1 \\ 0, t_4 < t_1 \end{cases} \quad (8)$$

d) Airspace overlap index E4

The overlap between the jamming signal action space and the receiver's useful signal acceptance range should be as large as possible[10].

$$E_4 = \begin{cases} S_g / S_y, S_g < S_y \\ 1, S_g \geqslant S_y \end{cases} \quad (9)$$

where S_g is the action space of the jamming signal; S_y is the acceptance range of the useful signal.

e) Jamming pattern index E5

Combined with prior knowledge, it is given subjectively according to the matching relationship between the jamming pattern and the interfered party.

f) Jamming method index E6

Given by the expert system according to the actual wartime situation.

4. TOPSIS ALGORITHM

TOPSIS algorithm has no strict requirements on data distribution, number of indicators and sample size in the evaluation process. The algorithm steps is shown as follows.

Step 1: Constructing decision matrix $A = (a_{ij})_{m \times n}$.

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mn} \end{bmatrix} \quad (10)$$

where a_{ij} represents the evaluation value given by the i-th scheme under the j-th evaluation index.

Step 2: Normalizing decision matrix.

The normalized decision matrix $B = (b_{ij})_{m \times n}$ is obtained by preprocessing the evaluation indexes with vector programming method.

where

$$b_{ij} = \frac{a_{ij}}{\sqrt{\sum_{i=1}^{m} a_{ij}^2}}, i = 1, 2 \cdots m, j = 1, 2 \cdots n \quad (11)$$

Step 3: Constructing Weighted normal matrix Z:

$$Z_{ij} = \omega_j \cdot b_{ij}, i = 1, 2, \cdots, m, j = 1, 2, \cdots n \quad (12)$$

where $W = [\omega_1, \omega_2, ... \omega_3]^T$ is weight vector.

Step 4: Calculating positive and negative ideal solutions z^+ and z^-:

$$z^+ = \left[z_1^+, z_2^+, \ldots, z_m^+ \right] \quad (13)$$

$$z^- = \left[z_1^-, z_2^-, \ldots, z_m^- \right] \quad (14)$$

where z_m^+ and z_m^- is the maximum and minimum of each column of the matrix Z.

Step 5: Calculating the Euclidean distance between each scheme and the positive and negative ideal solution. d_i^+ d_i^- represents the distance from the positive ideal solution and the negative ideal solution respectively.

$$d_i^+ = \sqrt{\sum_{j=1}^{m} \left(z_j^+ - z_{ij} \right)^2}, i = 1, 2, ..., m \quad (15)$$

$$d_i^- = \sqrt{\sum_{j=1}^{m} \left(z_j^- - z_{ij} \right)^2}, i = 1, 2, ..., m \quad (16)$$

Step 6: Calculating the distance between the scheme and the best scheme S_i.

$$S_i = \frac{d_i^-}{d_i^+ + d_i^-}, i = 1, 2, ..., m \quad (17)$$

where $0 \leq S_i \leq 1$, the smaller d_i^+ is, the bigger S_i is. Correspondingly, the smaller d_i^- is, the smaller S_i is. S_i also takes into account the distance between the scheme and positive and negative ideal solutions.

5. EXPERIMENTS AND RESULTS

Assuming that there are 6 jamming schemes. **Table 1** shows the basic performance parameters of the jamming system.

The unit of jamming signal power(P) is W, the unit of communication frequency (F) is MHz, the third column of the table is the jamming time (T) and the fourth column of the table is the jamming pattern (JP), it includes comb spectrum jamming (CSJ), sweep frequency jamming (SFJ), partial frequency band jamming (PFBJ), broadband noise jamming (BNJ). The fifth column of the table is the jamming method (MM), it includes tone jamming (TJ), noise FM jamming (NFJ), sawtooth sweep frequency jamming (SSJ), noise amplitude modulation jamming(NAJ).

Assuming that the communication system model is A, **Table 2** shows its basic performance parameters.

The signal power(P) is 50 W, the communication frequency (F) is 40~70MHz, the communication time (T) is 17:00~17:30 and the communication signal (MM) is MSK modulated signal.

Table 1 The jamming schemes.

	P	F	T	JP	MM
1	70	50~100	17:00~17:20	CSJ	TJ
2	30	55~110	17:15~17:40	CSJ	NFJ
3	50	30~90	17:24~17:45	SFJ	SSJ
4	120	45~55	17:12~17:35	PFBJ	TJ
5	105	50~80	17:20~17:40	BNJ	NAJ
6	60	0~65	16:50~17:35	SFJ	SSJ

Table 3. The preprocessing jamming indexes.

	E1	E2	E3	E4	E5	E6
1	0.600	0.667	0.667	0.500	0.755	1.000
2	0.067	0.500	0.500	0.500	0.660	0.792
3	0.333	1.000	0.200	0.500	0.630	0.848
4	1.000	0.333	0.600	0.500	0.236	0.396
5	1.000	0.667	0.333	0.500	0.330	0.396
6	0.467	0.833	1.000	0.500	0.760	1.000

Table 5. Judgment matrix *Z*.

	E1	E2	E3	E4	E5	E6
0	1.000	1.000	1.000	1.000	1.000	1.000
1	0.141	0.137	0.098	0.044	0.133	0.156
2	0.016	0.103	0.074	0.044	0.117	0.117
3	0.078	0.206	0.029	0.044	0.111	0.125
4	0.235	0.069	0.088	0.044	0.042	0.058
5	0.235	0.137	0.049	0.044	0.058	0.058
6	0.110	0.172	0.147	0.044	0.134	0.151
7	0	0	0	0	0	0

Table 2 Parameters of the communication system.

Model	P	F	T	MM
A	50	40~70	17:00~17:30	MSK

Table 4 The weighted and normalized jamming indexes.

	E1	E2	E3	E4	E5	E6
1	0.141	0.137	0.098	0.044	0.133	0.156
2	0.016	0.103	0.074	0.044	0.117	0.117
3	0.078	0.206	0.029	0.044	0.111	0.125
4	0.235	0.069	0.088	0.044	0.042	0.058
5	0.235	0.137	0.049	0.044	0.058	0.058
6	0.110	0.172	0.147	0.044	0.134	0.151

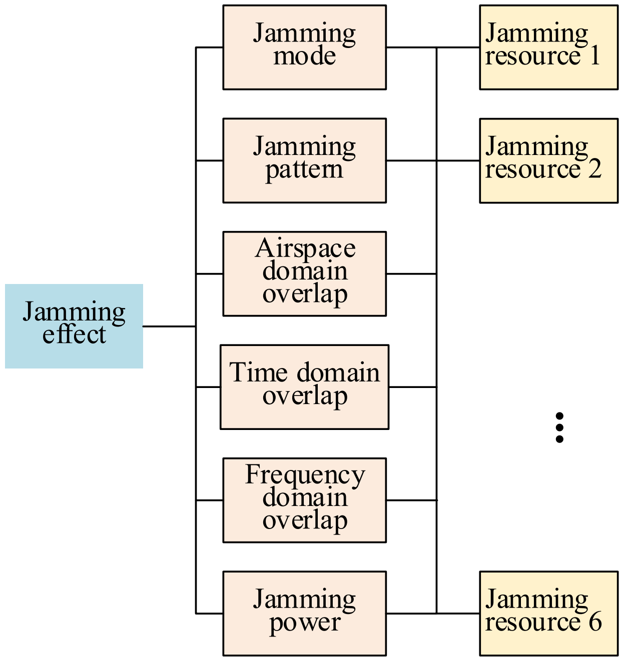

Fig.7 Hierarchy structure model of jamming effect index.

(1) Preprocessing data

Calculating the value of each jamming indexes, as shown in **Table 3**.

(2) Weight analysis of jamming indexes

a) Subjective weighting jamming indexes

Step 1: AHP was used to analyze the jamming effect in this paper, and the hierarchical model is shown in **Fig.7**.

Step 2: Calculating the weight vector. The eigenvector corresponding to the maximum eigenvalue of the judgment matrix *A* is the weight vector.

$$W = (0.235, 0.206, 0.147, 0.882, 0.177, 0.147)$$

b) Objective weighting the jamming indexes

In this paper, the objective weights of indexes are given based on Entropy Weight Method. The indexes weight vector is shown as follows.

$$W = (0.178, 0.164, 0.169, 0.158, 0.166, 0.165)$$

c) Subject-objective weighting the jamming indexes

Subject-objective weighting :

$$weights_i = \frac{a_i b_i}{\sum_{i=1}^{m} a_i b_i} \tag{18}$$

where a_i is objective weight, where b_i is subjective weight.

$$weights = (0.250 \;\; 0.200 \;\; 0.148 \;\; 0.083 \;\; 0.174 \;\; 0.144)$$

Table 4 shows the jamming indexes data after weighted and normalized by subject-objective weighting. The positive ideal solution of each index is 1 and the negative ideal solution is 0 after standardization. The problem of the interaction between the evaluation results of jamming effect of traditional TOPSIS algorithm is solved, and obtained the final judgment matrix Z is shown in **Table 5.**

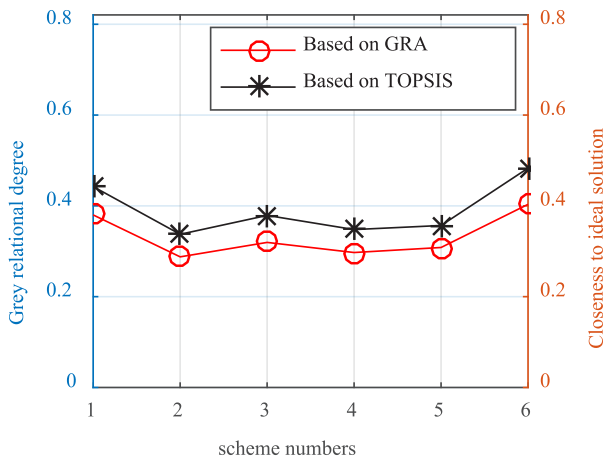

Fig.8 Jamming effect simulation results.

(3) Jamming effect evaluation

Grey system theory is a kind of system science theory, among which grey correlation analysis is a kind of multi-factor statistical analysis method. Based on the jamming index system proposed in this paper, the jamming effects of the grey correlation analysis proposed in reference[10] and the TOPSIS algorithm proposed in this paper were evaluated respectively. Simulation results as depicted in **Fig.8**.

The simulation results not only reflect the preference of the assessors on the importance of the evaluation indexes, but also make a comprehensive ranking of the jamming schemes based on the many evaluation indexes. The priority of the program is in the following order:scheme 6 > scheme 1 > scheme 3 >scheme 5 > scheme 4 > scheme 2.

The highest priority is given to scheme 6, which has the highest time domain overlap and the most matched jamming pattern. In scheme 1, jamming pattern has the biggest weight value, so it is better than the scheme 3. Power suppression of the scheme 2 has the largest deviation from the power suppression of the communication signal, which is more easily suppressed by the receiver, so the priority of scheme 2 is the smallest.

The results of the two jamming effectiveness evaluation algorithms are consistent, but the TOPSIS algorithm maximizes the use of the original data information, and its results can more accurately reflect the differences of each strategy.

6. CONCLUSION

This paper proposes a comprehensive evaluation method for the jamming effect of communication jamming systems. On the basis of the analysis of communication jamming signals, the jamming effect evaluation index system is established; then the subject-objective weighting method is used to weight the indicators to highlight the degree of influence of each index on the overall evaluation system; then a TOPSIS-based jamming program evaluation method; finally, by simulating the jamming effect evaluation based on the TOPSIS algorithm and the jamming effect evaluation based on the gray correlation degree, verified reasonable and feasibility of the jamming effect evaluation based on the TOPSIS algorithm proposed in this paper.

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