Generation and Performance Evaluation of Distributed Interference Based on Multiple-Wavelet

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Abstract. Sensor networks are groups of specialized transducers that have a communications infrastructure which is intended to record and monitor conditions at different locations. Sensor network are widely adopted in distributed interference because they are lightweight, small and extremely portable. In order to ensure the safety of civil aviation, it is necessary to control and disperse the unmanned aerial vehicle (UAV). This paper proposed the precise distributed interference for the UAV management and control by aggregating interference signal energy at the specific point and in the specific area. First, the distance between the distributed jammers and the target point is given, and the time of different wavelets reach the target point is calculated. Then the initial phases of all the wavelets are adjusted so as to ensure all the wavelets reaching the peak value at the specific point. Finally, the interference generated in specific area is proposed to meet practical application requirements. The experiment results demonstrate that the proposed distributed interference method can be used for precise interference under UAV management and control and even in the dynamic warfare environments.

Keywords: Distributed interference · Unmanned aerial vehicle (UAV) management and control · Energy aggregating · Wavelets cooperate

1 Introduction

Sensor networking technology is widely used in unmanned aerial vehicle (UAV) and electronic warfare, where a certain number of sensors are placed on the sea, on the ground or in the air with certain criteria to cooperate for a certain purpose [1]. As the civil unmanned aerial vehicles are used in various fields, Low-altitude and ultra-low-altitude airspace are becoming smaller and more complex, which brings huge security risks for other military and civilian aircraft [2, 3]. Therefore, the demand for precise air flight control system for civil UAVs is more urgent. Distributed precise interference is designed based on Multiple-wavelet system for the UAV management and control. Furthermore, in modern electronic warfare, the traditional conflict is changed into a struggle to seize the electromagnetic advantage in wireless confrontation [4, 5]. In order

B. Li et al. (Eds.): IoTaaS 2019, LNICST 316, pp. 537–548, 2020.
https://doi.org/10.1007/978-3-030-44751-9_45

to ensure the electronic equipment of the cooperative targets normally operating and non-cooperative targets are effectively interfered, we need to perform accurate interference [6]. The principle of electronic interference is to transmit an electromagnetic signal. That is, the transmitter transmits an interference signal with enough power and it is received by the non-cooperative target receiver. If the non-cooperative target is effectively interfered, it will inevitably lead to the loss of operational capability and even paralysis [7, 8]. As the rapid changes in the electronic warfare environment, we have to develop a technology that can adapt to the characteristics of electronic warfare [9]. It can dynamically make the interference signal energy aggregate in a specific area to achieve precise interference. How to arrange various types of reconnaissance and interference units according to the operational tasks in practical applications is a key technology in distributed precision interference [10, 11]. Through the arrangements of various interference sources in the air, on the ground and on the sea, theoretically the interference can operate at the target area and artificially implement accurate interference [12]. In distributed interference, the coherent signals are transmitted through the transmit antennas to accurately aggregate energy into a specific target area while ensuring that the cooperative targets are not affected [13]. Existing interference technologies mainly include: beamforming technology, sidelobe cancellation technology and waveform diversity technique. In the beamforming technology, the useful signal and the useless signal are considered to be separated, so that a beam with better performance can be formed in the direction of the enemy [14, 15]. However, in practical environment, useful and useless signals always intertwined and the useful signal is also affected while suppressing the useless signal, thereby the performance of beamforming technology is reduced. In the sidelobe cancellation technology, the performance of sidelobe cancellation system is related to the signal-to-noise ratio of the input signal under stable conditions. The larger the signal-to-noise ratio is, the deeper the depression is. Therefore, when the noise is relatively large and the signal-to-noise ratio is low, the suppression of useless signal effect is degenerated [16, 17]. In the waveform diversity techniques, the accuracy is improved at the expense of reducing the effective interference area. In addition, the algorithm of waveform diversity technology is quite complex and requires strong mathematical and computational ability [18, 19]. Therefore, in the practical applications, more realistic influencing factors need to be considered and the research is more complicated [20]. Aimed at the precise UAV management and control and the modern electronic warfare, this paper proposes a novel generation method of accurate interference at specific points and specific areas by aggregating coherent multi-frequency signals.

2 Distributed Interference

Wireless communication spreads signals through open structure, breaks the limitation of traditional closed transmission of wired structure and overcomes the lack of dynamics of wired structure, thereby meeting the demand for rapid information interaction. The distributed interference has two distinct advantages: one is that the cooperation capability between the devices is improved and the other is that the usage of energy is greatly improved.

2.1 Distributed Jammer Structure

The distributed jammer is mainly composed of a power supply, an interference signal generator, a power amplifier and transmitting antennas. Controllers can control the timing and combination of the generation of interference signals. Compared with the centralized interference system, it can effectively solve the problem that the interference signal interferes the cooperate targets when the transmission power of the interference signal is very strong. In addition, the distributed jammer is light and convenient, so it can be placed in the enemy's deep area, away from the radar and other reconnaissance communication equipment of cooperator. Therefore, the distributed interference technology effectively solves the problem that the interference signals interfere the enemy and interfere the cooperator at the same time. Following is the structure of the distributed jammer (Fig. 1).

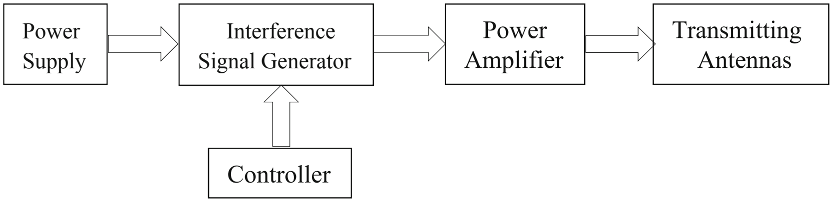

Fig. 1. Structure of the distributed jammer

According to the signal strength of distributed interference signals, we divide the interference into three broad categories: repressive interference, strong interference and weak interference.

Repressive interference: the power of the interfered signal is far less than the power of the interference signal, and the interfered target generally cannot work normally in the frequency band of the interference effect and the error rate is higher than 50%.

Strong interference: The distributed jammer uses a strong power interference signal to interfere the electronic equipment of non-cooperative targets. The power of the interfered signal is less than the power of the interfered signal. Therefore, the interfered equipment is basically difficult to work normally at the interference frequency, and the error rate is between 15% and 20%.

Weak interference: The distributed jammer adopts a low power electromagnetic interference to interfere the electronic equipment of non-cooperative targets. The signal received by the non-cooperative targets is mixed with the interference signal. Because the strength of the interference signal is low, it is impossible to completely suppress the signal and the error rate is about 3%–5%.

2.2 Distributed Interference Characteristics

Compared with traditional centralized jammers, distributed interference has clear advantages in three areas:

First of all, in terms of distribution, the traditional interference adopts the high-power interference jammer, which causes it easily detected and treated as an attack target by enemy equipment while interfering with the enemy. When the number of interference sources is large, and the distribution is very wide, the distributed interference will not be damaged even if they are attacked.

In terms of cost, the distributed interference cost is low for its circuit hardware is simple. Since only certain targets that interfere with the enemy are required during the interference process, there is no strict requirement for the power and form of the interference signal released by the interference source.

In terms of distance, the distance of distributed interference is close for its structure and other problems, generally belonging to near-field interference. The power lose is small for short interference distance, and the interference power entering the interfered radar is large, so the probability of effective interference is greatly improved.

3 Multi-frequency Signal Cooperative Interference

3.1 Multi-signal Superposition Principle

In signal superposition, we pay attention to the frequency and amplitude after signal superposition. In the superposition of multiple signals principle, the amplitude of signal is the arithmetic addition of multiple signals at that time. In addition to the amplitude of the signal, the periodicity of the signal after signal superposition is also important.

For the latter introduction of multi-signal superposition theory, we first introduce the superposition principle of a simple sinusoidal signal, that is to give the further introduction of periodic signals superposition. The periodic signal has some properties: the periodicity is not affected by the multiplication effect but after the addition the periodic uncertainty is generated. According to the knowledge in digital signal processing, we know that if the ratio of the two periodic signal period is a rational number, after the addition the two periodic signal is 100% of the periodic signal. The period of the new signal is the least common multiple of the initial signal period.

For the sake of intuition, it is assumed that the period of the periodic signal $f(t)$ is T_0, the period of the periodic signal $g(t)$ is T_1, when the ratio between the T_0 and T_1 is a rational number, the new signal period T is a multiple of their period, that is, T is both the integral multiple of the period T_0 and the period T_1, and certainly $f(t)+g(t)$ satisfies the regularity of the period. Furthermore, from the perspective of the frequency domain, the Fourier transform of the periodic signal is equivalent to equally spaced sampling of its spectrum, and the sampling interval of the frequency domain is $\frac{2\pi}{T}$, and the spectrum of the superposed signal is the accumulation of the impact sequence generated by the initial signal sampling. When the initial signal period ratio is a rational number, the ratio of the interval sampling is a rational number. The new spectral interval formed by the superimposed impact sequence is uniform, otherwise the interval changes with frequency.

The simulation parameters are set to simulate the superposition of multiple sinusoidal signals with different initial frequencies and zero sinusoidal signals in the same frequency at different frequencies. The superposition of multiple signals with the same frequency interval is also simulated. Their respective periods are 2π, π, $\frac{2}{3}\pi$, $\frac{1}{2}\pi$, $\frac{2\pi}{n}$, n is the number of the superposition signals (Figs. 2 and 3).

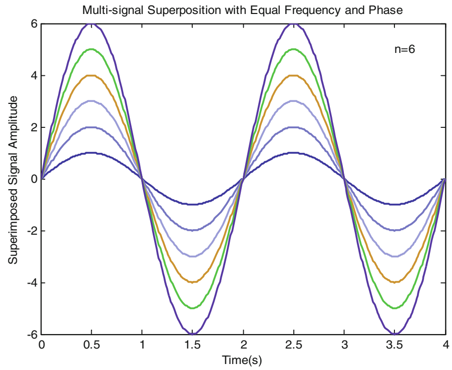

Fig. 2. Multi-signal superposition with equal frequency and phase

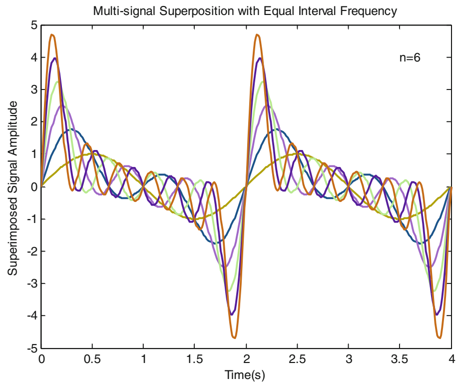

Fig. 3. Multi-signal superposition with equal interval frequency

It can be seen form the comparison of the simulation diagrams that as the number of superimposed signals increases, the amplitude of the superimposed signal increases, and the directivity of the signal increases. When the number of superposition signals is the same, in the simulation based on the superposition of multiple signals with same frequency, the amplitude after signal superposition is multiplied, but its main lobe width is wide and the directivity is poor. In the simulation based on the superposition of multiple signals with equal interval frequency, the amplitude is not multiplied increasing after the signal superposition, but the directivity of the superimposed signal is significantly enhanced. We are eager to find a way to equalize the amplitude and directivity, where the peaks of all the signals at the target point are superimposed. After adjusting the initial phases of the wavelets, the peak of each wavelet signal arriving is superimposed at the target point. This method is named as multi-signal superposition energy aggregation.

3.2 Multi-frequency Signal Cooperative Interference Model

In order to better aggregate the energy and achieve better interference effect, the multi-frequency signal superposition energy aggregation interference strategy is adopted. In this section, the transmitted signal is not a single frequency signal, and the transmitted signal consists of multiple equal interval frequency wavelets. All the wavelets with different frequencies properly adjust their initial phases so that all the wavelet reach the peak value at the position of the interference target (the receiver of the other party). In this way, the energy of all the wavelet reaches the peak value, the interference signal energy is coherently superimposed, and the interference effect achieves better.

Interference at the Specific Point. In the implementation of interference, we must clear the position of the target point, and change the initial phase of the wavelets with different frequencies according to the distance between our transmitter and the enemy receiver, so that when the wavelets of different frequencies arrive at the enemy receiver, the energy reaches the peak value. The energy of each wavelet is fully utilized and plays a positive role in the interference. Interference cancellation occurs at non-target points for the cooperative of wavelets of different frequencies in this process, so that the energy of the wavelets of different frequencies is maintained at zero in the non-target position. We can place our own equipment at these positions, which has a good application prospect. We summarize the above process in the following steps (Fig. 4):

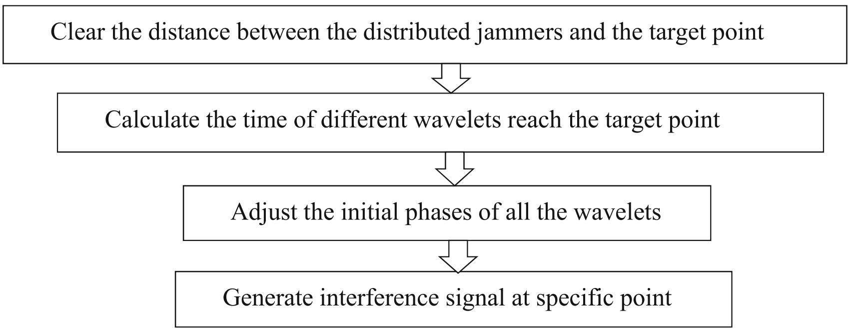

Fig. 4. The process of interference generated at the specific point

Firstly, we should clear the distance D between the distributed jammers and the target point, then calculate the time of different wavelets reach the target point with the formula $\Delta t = \frac{D}{C}$, where C is the electromagnetic wave transmission speed and $c = 3.0 \times 10^8$. Adjust the initial phase according the formula $\Delta\varphi_n = -2\pi f_n \, \Delta t$, in this way, the energy of different frequency wavelets arrives at the target point with peak energy value.

Interference in Specific Area. In practical applications, the actual interference area is not just a point. Therefore, interference at the specific point often cannot meet the actual requirements. We hope that the interference area can be flexibly adjusted according to the actual requirements, in addition to the peak energy aggregate at the fixed point. Interference in specific area can accurately interfere with the destruction of enemy equipment in small areas, while protecting our own equipment in the nearby area to work properly, improving the efficiency and accuracy of interference. Therefore, compared with the interference at the specific point, the interference in specific area with adjustable interference area is more applicable in engineering. We summarize the process in the following steps (Fig. 5):

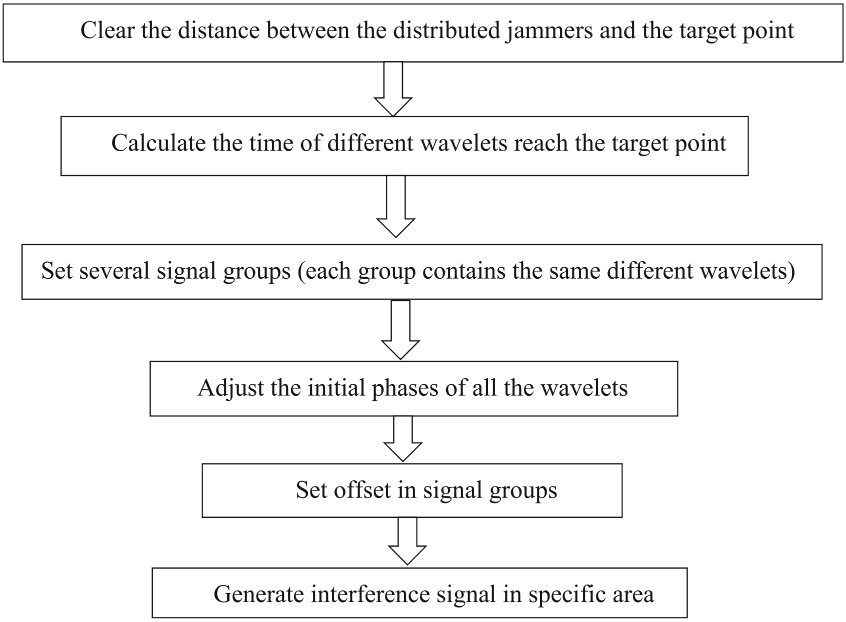

Fig. 5. The process of interference generated in the specific area

Firstly, we should clear the distance D between the distributed jammers and the target point according to the positioning reconnaissance equipment. It is assumed that all wavelets travel at the same speed in the air and equal to the speed of light. The time of different wavelets reach the target point with the formula $\Delta t = \frac{D}{C}$, where C is the electromagnetic wave transmission speed. In order to implement interference in specific area, we set several groups of signals, each group containing the same different frequency wavelets. The number of wavelet groups N is uncertain, but the more groups, the better interference accuracy. Adjust the initial phase according the formula $\Delta\varphi_n = -2\pi f_n \Delta t$, when the wavelets reach the target point, adjust the initial phase of the wavelets to form a peak. Finally, at the receiver position, each signal group slightly adjusted the wavelets phase so that the aggregate points of the plurality of wavelet groups are evenly distributed around the interference point.

4 Simulation and Analysis

4.1 Interference at the Specific Point

Set the parameters for simulation is as following: The principle for UAV management and control is to generate precise interference. Considering the actual application scenarios, the distance between the interference jammers and the target receiver is assumed 700 m. 16 and 48 equal interval frequency wavelets are set respectively and the lowest frequency is 2.0×10^5 Hz and the electromagnetic wave transmission speed is 3.0×10^8 m/s. The one-dimensional and three-dimensional simulation are as follows:

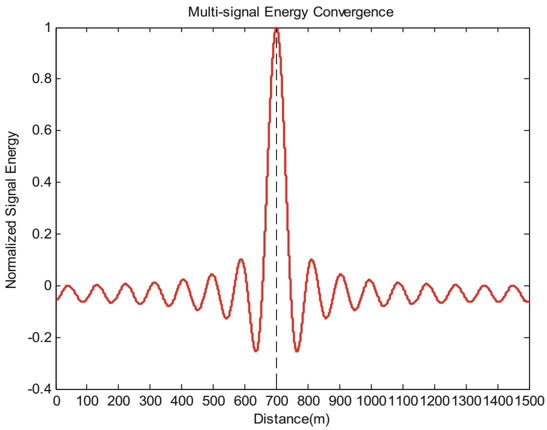

Fig. 6. The one-dimensional figure of energy convergence with 16 equal interval frequency wavelets

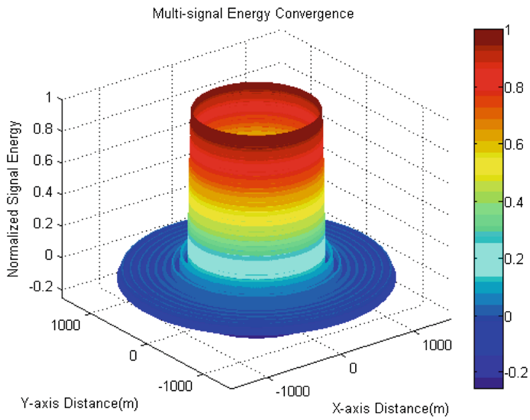

Fig. 7. The three-dimensional figure of energy convergence with 16 equal interval frequency wavelets

It can be seen from the Figs. 6 and 7 that multiple wavelets can interfere with the equipment at the specific points according to requirements. However, the interference is not accurate for the main lobe of the interference energy is relatively fat and the directivity is poor.

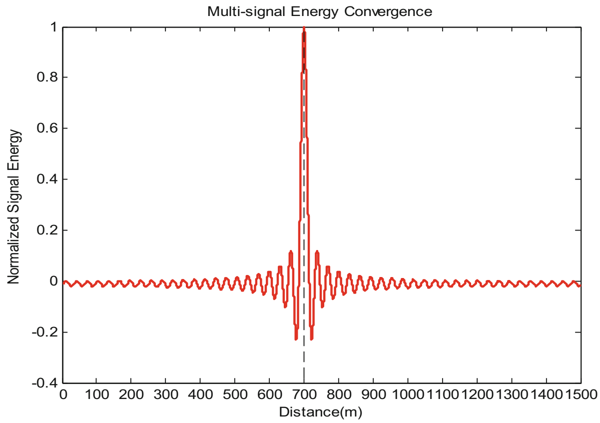

Fig. 8. The one-dimensional figure of energy convergence with 48 equal interval frequency wavelets

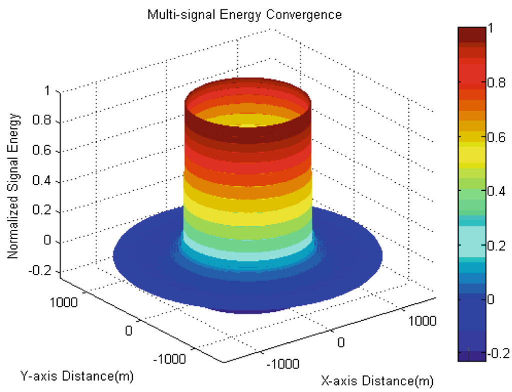

Fig. 9. The three-dimensional figure of energy convergence with 48 equal interval frequency wavelets

It can be seen from the Figs. 8 and 9 that multiple wavelets can interfere with the equipment at the specific points according to requirements. When the number of the wavelets is 16, the accuracy of interference is relatively poor, and the main lobe is relatively fat. When the number of the wavelets is 48, the interference is more accurate and the main lobe is thinner. That is to say, as the number of wavelets increases, the interference becomes more and more accurate, and the effect of interference becomes stronger and stronger. However, as the number of wavelets increases, the calculated amount increases and the speed of interference is slowed down.

4.2 Interference in Specific Area

Set the parameters for simulation is as following: It is assumed that the distance between the interference jammers and the target receiver is 800 m and the interference area is 400 m and 600 m respectively. 48 equal interval frequency wavelets are set and the lowest frequency is 0.75×10^5 Hz and the electromagnetic wave transmission speed is 3.0×10^8 m/s. The number of signal groups is 10. The simulation is as follows:

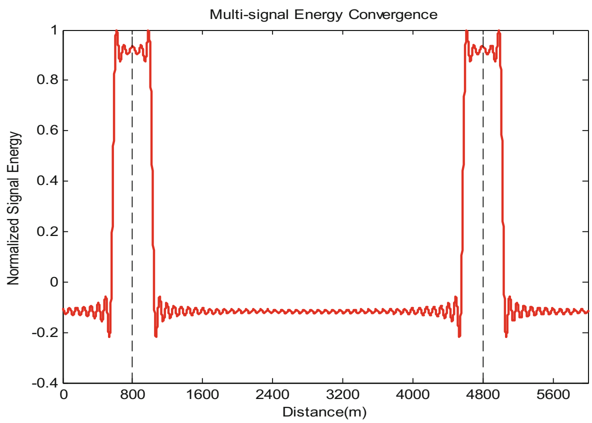

Fig. 10. Interference in specific area with width of 400 m

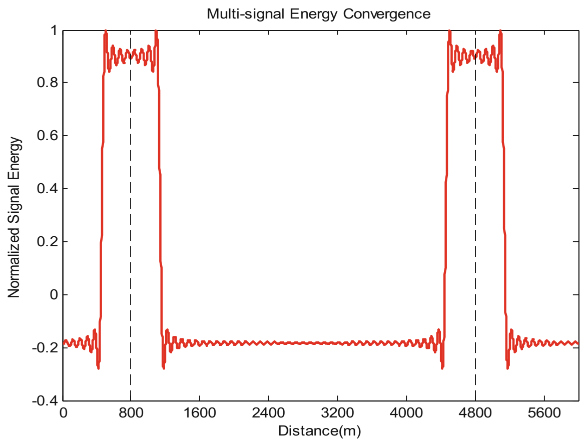

Fig. 11. Interference in specific area with width of 600 m

It can be seen from the Figs. 10 and 11 that interference with the width of 400 m and 600 m is generated near the target point of 800 m. We can see that in the interference region, the interference energy is aggregated, while the energy of interference at other locations is relatively weak. In practical applications, the cooperative interference parameters can be set according to the distance and distribution of the other devices, thereby implementing accurate interference based on interference regions.

5 Conclusion

Under the background of urgent demand of air flight control system for civil UAVs and precise electronic warfare, this paper proposed the accurate interference method, which can effectively interfere non-cooperative targets in a certain area, and cooperative targets in other areas are not affected. In this paper, a method of superimposing interference with multiple equal interval frequency wavelets is adopted to generate accurate interference at the specific point and in the specific area. The distance between the distributed jammers and the target point is provided by the cooperative device and the initial phase of the plurality of wavelets is adjusted so that the energy of the interference signal reaches the peak value. When different interference wavelets reach the target point, the energy of the multiple wavelets is aggregated to obtain accurate suppression interference. The simulation shows that the interference method proposed in this paper can generate effective interference at the target point and around the target point. Therefore, the distributed interference method proposed in this paper can be applied to practical applications.

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