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Analysis of spatial power synthesis efficiency based on the near-field cross-beam theory for distributed UAV interference applications

Key words: Spatial power synthesis; Near-field; Distributed UAV interference; Cross-beam synthesis

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Motivation

- Nowadays, the demand for small, highly maneuverable jamming systems has increased in response to a variety of interference targets and complex environments. Research on spatial power synthesis technology and factors affecting synthesis efficiency has been conducted to evaluate and improve damage power. However, previous studies are in ideal situations, and the number of research units is relatively small. A comprehensive analysis of the factors influencing the synthesis efficiency at target points is still lacking, as is the experimental verification.

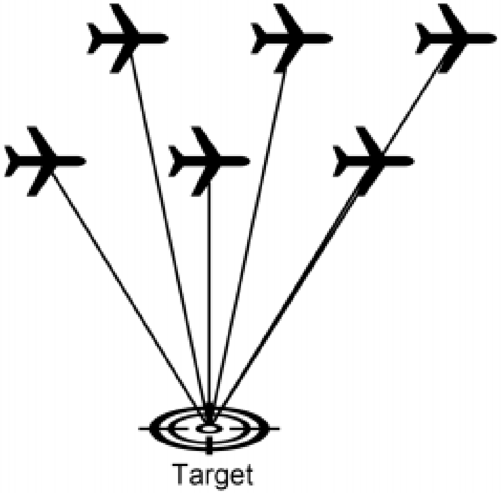


Fig. 1 Schematic of unmanned aerial vehicle (UAV) interference with the target

Main idea

- To address the synthesis efficiency of unmanned aerial vehicle (UAV) swarm, this paper combines power synthesis technology in free space with the theory of cross-beam synthesis. A comparison of the proposed method with traditional far-field calculation methods is conducted.
- The impact of parameters such as UAV positioning accuracy, attitude accuracy, time synchronization accuracy, and failure rate is also analyzed.
- A test scenario with time synchronization is designed, and spatial power synthesis efficiency is measured to provide experimental evidence for the proposed computational method.

Method

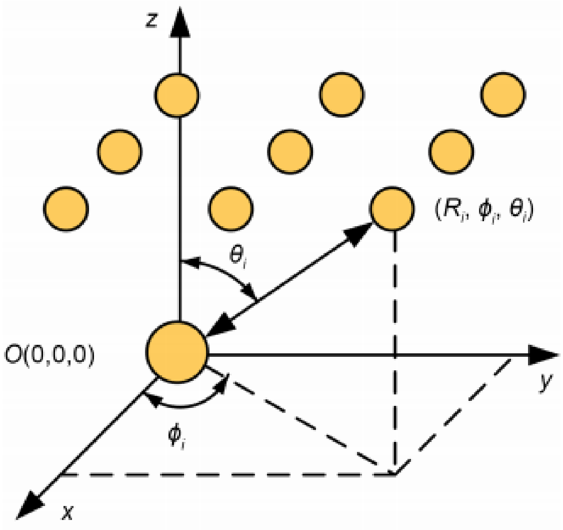


Fig. 2 Model of the distributed power synthesis

Cross-beam synthesis is reliable since the interference target is located in the near field of the antenna array based on $r=2D^2/\lambda$.

The decomposed electric field with the theory of cross-beam synthesis is obtained as

$$\begin{cases} E_{ix} = \Delta_c \dfrac{f_i(\theta_i,\phi_i)}{R_i}\cos(\theta_i)\cos(\phi_i)\mathrm{e}^{-(\varphi_0-\delta_i)}, \\ E_{iy} = \Delta_c \dfrac{f_i(\theta_i,\phi_i)}{R_i}\cos(\theta_i)\sin(\phi_i)\mathrm{e}^{-(\varphi_0-\delta_i)}, \\ E_{iz} = \Delta_c \dfrac{f_i(\theta_i,\phi_i)}{R_i}\sin(\theta_i)\mathrm{e}^{-(\varphi_0-\delta_i)}, \end{cases}$$

The spatial power synthesis efficiency is obtained as

$$\eta_{\text{cross}} = \frac{P_{\text{R}}}{P_{\text{R max}}} = \frac{|E|^2}{|E_{\max}|^2} = \sum_{i=0}^{N-1}\left(\frac{f_i(\theta_i,\phi_i)}{R_i}\right)^2$$
$$+\frac{1}{N^2}\sum_{i=0}^{N-2}\sum_{j=i+1}^{N-1}\left[\frac{f_i(\theta_i,\phi_i)}{R_i}\frac{f_j(\theta_j,\phi_j)}{R_j}\cos(\delta_i-\delta_j)\right.$$
$$\left.\cdot\left(\cos\theta_i\cos\theta_j\cos(\phi_i-\phi_j)+\sin\theta_i\sin\theta_j\right)\right].$$

Method

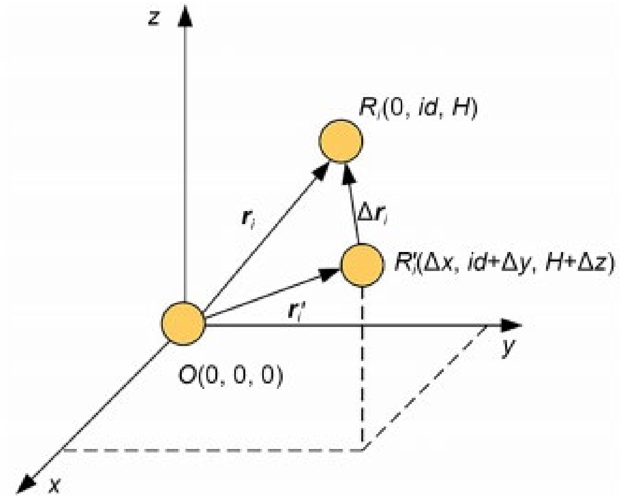
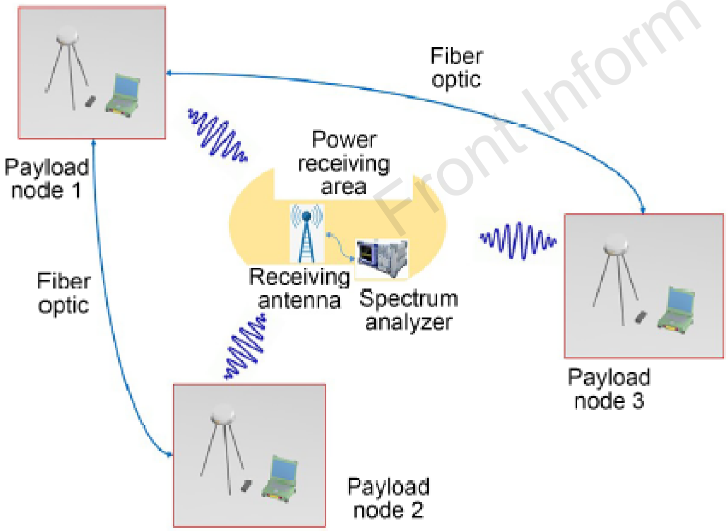


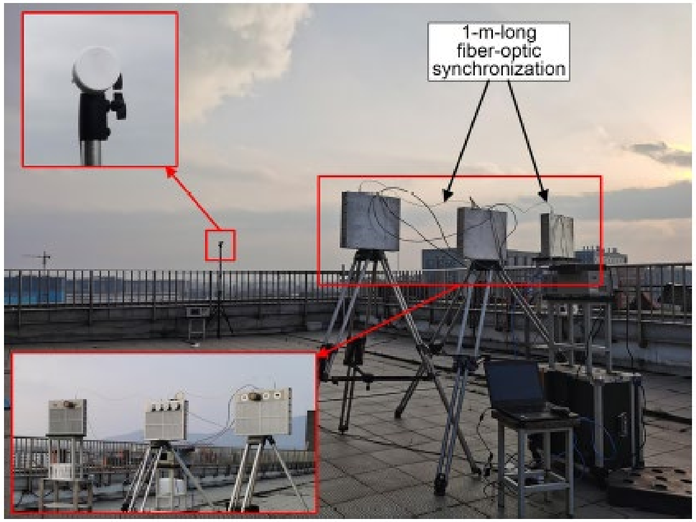
Fig. 3 Simulated model for the UAV position deviation

Impact factors on spatial synthesis efficiency, including payload carrier frequency, beam width, positioning error, attitude error, and UAV failure rate, are investigated.

An experiment was conducted to investigate the synthesis efficiency with a high time synchronization accuracy and a tiny positioning error.

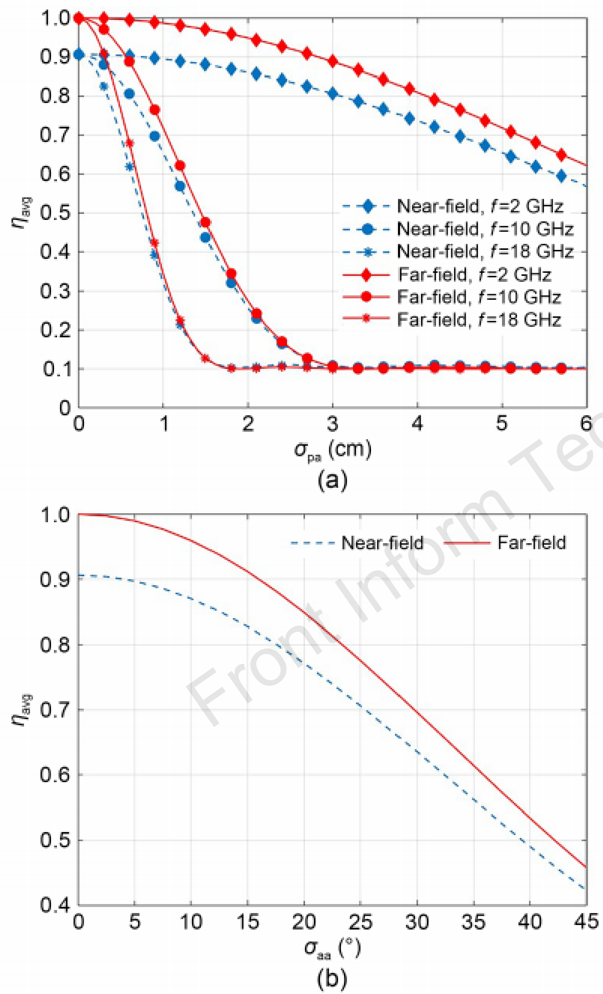


Test schematic



Test environment setup

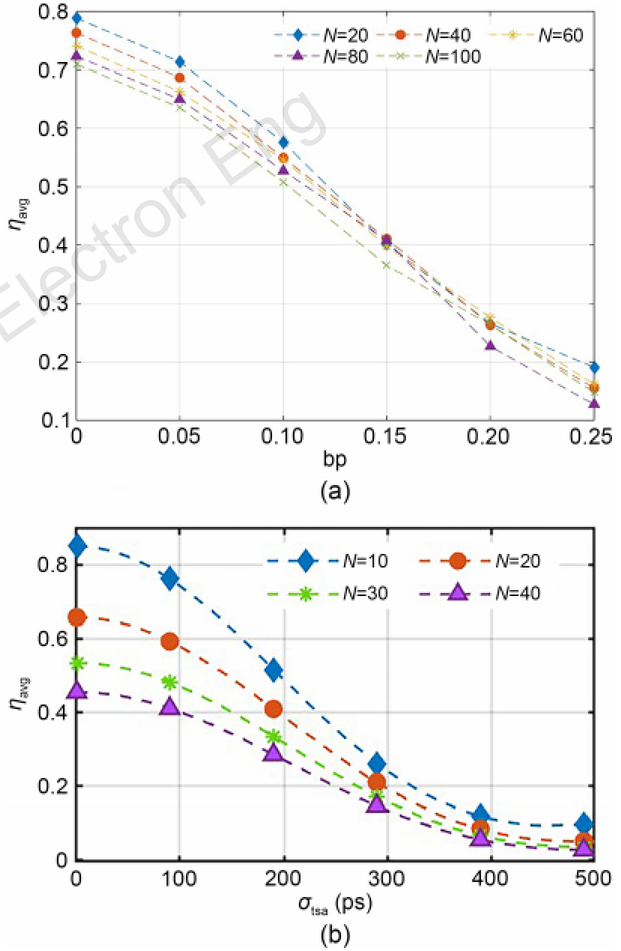
Results



(a)

(b)

Fig. 4 Relationship between the average synthesis efficiency with positioning accuracy (a) and attitude accuracy (b)



(a)

(b)

Fig. 5 Relationship between the average synthesis efficiency with UAV damage rate (a) and time synchronization accuracy (b) in the near field accuracy

Results

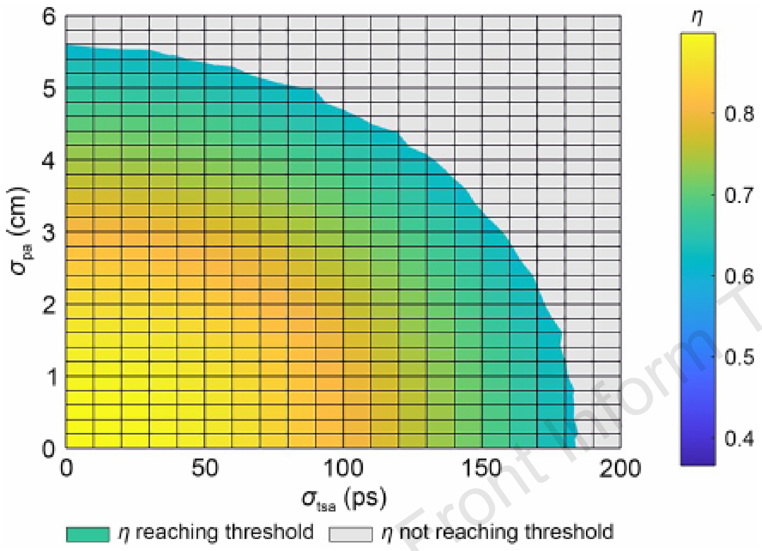


Fig. 6 Relationship between the average synthesis efficiency and time synchronization, as well as positioning accuracy

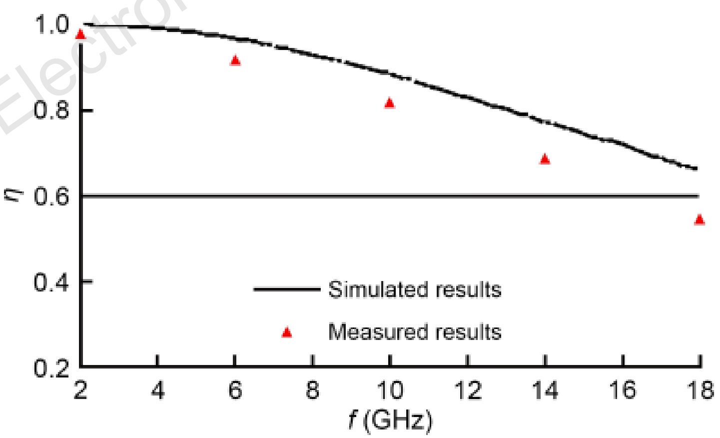


Fig. 9 Measured and simulated power synthesis efficiency

Conclusions

In this paper, the UAV swarm scenarios were modeled to analyze the impact of performance parameters of UAV platforms and their payloads on the spatial power synthesis efficiency. Specifically focusing on the near-field conditions, the synthesis efficiency was analyzed and tested. An experiment was designed and conducted to validate the reliability of the cross-beam synthesis method. The study in this paper provides a theoretical basis for the layout of low-altitude UAV interference systems and ultimately the improvement of interference efficiency at a certain point.

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