Energy-Efficient Subcarrier Allocation and Power Optimization Method for UAV Swarms

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Abstract. In recent years, the increasing deployment of unmanned aerial vehicles (UAVs) has highlighted their adaptability and operational flexibility, gaining substantial interest across academia and industry. Nonetheless, interference within UAV swarms has emerged as a critical challenge that could potentially hinder further performance enhancements. To address this issue, this paper introduces a robust interference management and resource optimization framework. Initially, the study develops a comprehensive model that simultaneously addresses the impact of interference from both establishing new links and affecting existing ones. This paper also presents a strategy for optimal subcarrier selection aimed at minimizing deterministic interference and delineates the threshold number of carriers needed for interference-free operations. Additionally, it outlines an innovative power allocation scheme to further enhance system efficiency. Simulation results confirm that the proposed subcarrier allocation strategy significantly outperforms conventional approaches in terms of energy efficiency and throughput, marking a notable advancement in UAV communication systems. This paper's findings promise to refine operational protocols and optimize UAV network performance, presenting a pivotal step towards mitigating interference in UAV swarms.

Keywords: Interference analysis · Subcarrier allocation · Resource allocation · UAV swarms

1 Introduction

In recent years, UAVs have garnered widespread attention in both academic and industrial fields due to the exceptional flexibility, high maneuverability, and on-demand deployment capabilities. Therefore, UAV-enabled communication applications are expected to play a significant role in future wireless networks.

Supported by National Natural ScienceFoundation of China No. 62431009 and No. 62271168 and the Key R&D Plan of Heilongjiang Province of China under Grand No. JD22A001.

H.-H. Chen and W. Meng (Eds.): WiSATS 2024, LNICST 606, pp. 202–214, 2025.
https://doi.org/10.1007/978-3-031-86203-8_17

UAVs are considered capable of fulfilling various application demands, including information collection and dissemination, target tracking, and environmental sensing. Compared to a single UAV, a swarm of UAVs not only overcomes the hardware limitations of a single UAV, but also enhances the fault tolerance of the entire system [1]. Although the applications of UAV swarms are increasing and attracting attention, the frequent communication demands within the swarm can lead to interference issues among UAVs, which will become a bottleneck in improving performance. Therefore, interference control and resource optimization are crucial for UAV swarms.

Some studies have focused on interference management in UAV networks, proposing various interference mitigation and resource optimization methods. To evaluate the impact of UAV network distribution on coverage performance, the literature [2] proposes a stochastic geometry-based approach to model interference distribution in UAV networks. The research results indicate that inter-group interference in UAV networks becomes non-negligible when the high-density drone deployment occurs. Another study [3] proposes a multi-agent reinforcement learning-based UAV swarm communication scheme to optimize relay selection and power allocation to counter interference. Additionally, the issue of joint UAV-cell association and transmission power control under multi-cell interference is considered, with a scheme proposed to maximize network throughput. For uplink multi-antenna UAV communication systems, literature [4] an interference cancellation strategy utilizing limited backhaul links between adjacent ground base stations is proposed to eliminate uplink co-channel interference from UAVs. Study [5] addresses joint resource optimization under adjacent channel and external interference in UAV communication, proposing an alternating optimization method to solve the adjacent channel interference problem. A multi-UAV-assisted downlink cellular network is investigated in literature [6], applying continuous convex optimization to jointly optimize UAV resource allocation and positioning to improve downlink data rates. Furthermore, an interference-aware UAV path planning scheme is proposed in [8], along with a deep reinforcement learning algorithm based on echo state networks to address the dynamic game between network delay and ground network interference.

Despite the relevant research providing some solutions to interference problems, certain issues remain unaddressed. Firstly, tasks within a UAV swarm do not usually arrive simultaneously, necessitating consideration of the impact on established links when determining optimal interference management and resource allocation schemes. Moreover, due to information transmission among UAVs, UAV nodes can utilize information from neighboring nodes to assess the extent of interference signals during interference management, allowing for more accurate interference management schemes. The main contributions of this paper are summarized as follows:

1. The model considers the interference situation of resource allocation schemes on original links. Additionally, the interference is divided into deterministic and random components based on information obtained from neighboring UAVs through adjacent nodes.

2. The impact of deterministic and random interference components on received signals is separately studied. The statistical characteristics of the power distribution for random interference components are established. For deterministic interference components, an optimal subcarrier selection scheme is proposed, considering the impact of carrier selection on both the current and established links, and the boundary of subcarrier count under interference-free conditions is proven. Based on this boundary, optimal allocation schemes are provided for different numbers of system carriers.
3. An optimal power allocation scheme is proposed for scenarios with a large number of system carriers. Simulation results show that the proposed subcarrier allocation scheme has advantages in energy efficiency and throughput performance compared to benchmark schemes.

2 System Model

This paper considers a system within a UAV swarm where a service needs to be transmitted from the UAV S to the destination UAV D, with a required transmission rate r_k. It is assumed that the total available system bandwidth is W, which is evenly divided into M subcarriers, each with a bandwidth of $w = W/M$. With $\mathcal{W}_k = \{1, 2, \ldots, W\}$ representing the set of subcarriers, the paper defines $\mathcal{U}_k$ as the set of subcarriers used by the k-th UAV and $\mathcal{A}_k$ as the set of unused subcarriers. The set of neighboring UAVs to the UAV k is represented by $\mathcal{R}_k = \{j \mid d_{k,j} < d_{\max}\}$, where $d_{\max}$ represents the maximum communication range. Due to hardware limitations, a UAV can only establish communication links with K neighboring UAVs simultaneously. Thus, during information exchange, UAV k can only obtain information from K UAVs within $\mathcal{R}_k$ and establish communication links with UAVs within $\mathcal{R}_k$ through one subcarrier.

Due to the line-of-sight transmission characteristics between UAVs, the channel between UAVs is often depicted using a large-scale fading model. Therefore, the channel $h_{k,j}(t)$ between the UAV k and the UAV j can be expressed as

$$h_{k,j}(t) = \beta_0^m d_{k,j}^{-2}(t). \tag{1}$$

This paper assumes that UAVs in the swarm are uniformly distributed, so the distance to the K nearest UAVs from the UAV k can be approximately modeled as a Poisson distribution. $s_k(t)$ and $p_k(t)$ respectively represent the transmission symbol and transmission power of the UAV k at time t, the transmission signal of UAV k can thus be expressed as $x_k(t) = \sqrt{p_k(t)} s_k(t)$. The superscript m represents the subcarrier of the transmission signal from UAV k, and the subscript j denotes the receiving UAV, $j \in \mathcal{R}_k$. The received signal of UAV j can be expressed as

$$\begin{aligned} y_{k,j}(t) = & \underbrace{h_{k,j}^m(t)\sqrt{p_k(t)}s_k(t)}_{\text{expected signal}} + \underbrace{\sum_{i\in\mathcal{K}} u_i^m(t)h_{i,j}^m(t)\sqrt{q_i(t)}s_i(t) + n}_{\text{interference}} \\ & = h_{k,j}^m(t)\sqrt{p_k(t)}s_k(t) + \underbrace{\sum_{i\in\mathcal{R}_j, i\neq k} u_i^m(t)h_{i,j}^m(t)\sqrt{q_i(t)}s_i(t)}_{\text{determinative interference}} \\ & + \underbrace{\sum_{l\notin R_j, l\in\mathcal{K}} u_l^m(t)h_{l,j}^m(t)\sqrt{q_l(t)}s_l(t) + n}_{\text{random interference}}. \end{aligned} \tag{2}$$

Since some communication links have already existed before establishing the current link, the receiver of UAV j not only receives the transmission signal from UAV k but also contains interference signals from other UAVs in the network. Depending on whether the interference source is within the communication range of the UAV, the interference can be categorized into deterministic and random interference components. For the deterministic interference component, the UAV can identify which subcarrier the interference source comes from, $u_i^m(t)$ and $h_{i,j}^m(t)$ can be considered as known constants. In the random interference component, both $u_i^m(t)$ and $h_{i,j}^m(t)$ are random parameters, and the UAV can only obtain the statistical properties of the interference. The subscript i represents other UAVs in the swarm that are not in set $\mathcal{R}_k$, and $q_i(t)$ represents the transmission power of the interference signal. $u_i^m(t)$ is a binary indicator variable that takes a value of 0 or 1, defined as

$$u_i^m(t) = \begin{cases} 1, & \text{UAV } i \text{ use resource } m \\ 0, & \text{UAV } i \text{ does not use resource } m. \end{cases} \tag{3}$$

Based on the received signal model given by (2), the signal-to-interference-noise ratio (SINR) obtainable by the receiver UAV j can be expressed as

$$\text{SINR}_{k,j}(t) = \frac{|h_{k,j}(t)|^2 p_k(t)}{\sum_{i\in\mathcal{R}_j, i\neq k} u_i^m(t)\,|h_{i,j}(t)|^2 q_i(t) + I_{k,j}(t) + \sigma^2}, \tag{4}$$

where σ^2 represents the noise power and $I_{k,j}(t)$ is the expected value of the random interference component at UAV j, expressed as

$$I_{k,j}(t) = \mathbb{E}_{\mathbf{u},\mathbf{l},\mathbf{p}}\left[\sum_{i\notin R_j, i\in\mathcal{K}} u_i^m(t)\left|h_{i,j}^m(t)\right|^2 q_i(t)\right]. \tag{5}$$

Therefore, the transmission rate between UAV k and j can be expressed as

$$R_{k,j}(t) = w\log\left(1 + \text{SINR}_{k,j}(t)\right). \tag{6}$$

In the UAV swarm, whenever a new communication link is established, the existing links will be affected by the interference from the new link. The interference power caused by UAV k to UAV j can be expressed as

$$T_{k,j}(t) = u_j^m \left|h_{k,j}^m(t)\right|^2 p_k(t). \tag{7}$$

Considering the limited battery capacity of UAVs and the fact that the UAV network is an interference-limited system, this paper aims to minimize power consumption while meeting real-time service communication rate requirements by considering subcarrier selection and power control issues. Define the variable $\alpha_{k,j}$ as an indicator for the UAV k sending signals to the UAV j, which is a binary variable that takes a value of 0 or 1, and satisfies the following conditions

$$\alpha_{k,j} \triangleq \begin{cases} 1, & \text{UAV } k \text{ sends a signal to UAV } j, \\ 0, & \text{otherwise.} \end{cases} \tag{8}$$

The issue studied in this paper can be expressed as

$$\begin{aligned} & \min_{\left\{u_j^m\right\}_{j\in\mathcal{K}}, \{p_k(t)\}_{\forall k\in\mathcal{K}}, \{\alpha_{k,j}\}_{\forall k,j\in\mathcal{K},k\neq j}} \sum_{k\in\mathcal{K}} \int_t \alpha_{k,j} p_k(t) dt \\ & \mathcal{C}1: \sum_{j\in\mathcal{K},j\neq S} \alpha_{S,j} = 1, \\ & \mathcal{C}2: \sum_{k\in\mathcal{K},k\neq D} \alpha_{k,D} = 1, \\ & \mathcal{C}3: \left(\sum_{k\in\mathcal{K},k\neq j} \alpha_{k,j} + \sum_{l\in\mathcal{K},j\neq l} \alpha_{j,l} - 2\right) \\ & \qquad \times \left(\sum_{k\in\mathcal{K},k\neq j} \alpha_{k,j} + \sum_{l\in\mathcal{K},j\neq l} \alpha_{j,l}\right) = 0, \forall j \in \mathcal{K}, j \neq D, j \neq S, \\ & \mathcal{C}4: \alpha_{k,j} + \alpha_{j,k} \leq 1, \forall k, j \in \mathcal{K}, k \neq j, \\ & \mathcal{C}5: R_{k,j}(t) \geq r_k, \forall k \in \mathcal{K}, \\ & \mathcal{C}6: \max_{j\in\mathcal{R}_k} u_j^m \left|h_{k,j}^m(t)\right|^2 p_k(t) \leq \eta_{\text{int}}. \end{aligned} \tag{9}$$

The constraints $\mathcal{C}_1, \mathcal{C}_2$ are separately to ensure that the source UAV S can transmit the data flow and the destination UAV D can receive the data flow. The constraint $\mathcal{C}_3$ is to ensure that a connected transmission path can be found, and the constraint $\mathcal{C}_4$ is to ensure the unidirectional link transmission. The constraints $\mathcal{C}_1 \sim \mathcal{C}_4$ constitute the conditions ensuring routing transmission. The constraint ensures that the identified link can achieve the service transmission, and the constraint $\mathcal{C}_5$ ensures that the maximum interference power of the UAV does not exceed a certain tolerance threshold η_{int}, to reduce the impact on existing communication links. Due to u_j^m being a binary integer variable taking values 0 or 1 and the complex coupling relationships between variables, solving this problem is relatively complex. Therefore, the following chapters will provide a detailed explanation of the proposed solution methods.

3 Joint Subcarrier Selection and Power Optimization Method

For a given link transmission method $\alpha_{k,j}$, the subcarrier selection and power optimization problem can be expressed as

$$\begin{aligned} &\min_{\{p_k(t)\}_{\forall k \in \mathcal{K}}, \{u_k^m\}_{\forall k \in \mathcal{K}}} \sum_{k \in \mathcal{K}} \int_t p_k(t) dt \\ &\mathcal{C}1 : R_{k,j} \geq r_k, \forall k \in \mathcal{K}, \\ &\mathcal{C}2 : \max_{j \in \mathcal{R}_k} u_j^m \left| h_{k,j}^m \right|^2 q_j(t) \leq \eta_{\text{int}}. \end{aligned} \tag{10}$$

Since $u_k^m \in \{0, 1\}$ is an integer variable, traditional methods based on convex optimization are difficult to apply directly. Considering that subcarrier allocation only affects interference, the following research will consider the impact of subcarrier allocation on both random and deterministic interference components separately.

3.1 Performance Analysis of Random Interference

According to (5), the main factors affecting the random interference component are the subcarrier allocation scheme $u_i^m(t)$, the channel gain $\left| h_{i,j}^m(t) \right|^2$, and the transmission power $q_i(t)$.

For the subcarrier allocation $u_i^m(t)$, since UAVs do not have prior information about $u_i^m(t)$ in the random interference component, the study considers the assumption of uniform allocation of subcarriers in the network.

The channel gain $\left| h_{i,j}^m(t) \right|^2 = \beta_0^m d_{i,j}^{-2}(t)$ and the transmission power $q_i(t)$ are random variables related to the communication distance between UAVs. In this study, it is assumed that UAVs within the study area follow a spatial Poisson point process Φ_u with a density of λ_u. According to Slivnyak's theorem, the probability density function of the distance d_I between UAVs is $p_{d_I}(x) = 2\pi\lambda_u \exp\left(-\pi\lambda_u x^2\right)$, with a mean of λ_u. Therefore, the sum of the random interference received by UAV j can be expressed as $I_{k,j} = \mathbb{E}[\sum_{r > R_K} |h_{i,j}^m(t)|^2 q_i(t)]$, and the moment generating function of the interference power can be expressed as $M_{P_I}(\frac{r_k}{P_s l(\lambda/K)})$, where

$$M_{P_I}(z) = \exp\left(-2\pi\lambda \int_{\lambda u/K}^{\infty} \frac{r}{1 + \left[z P_s l(r)\right]^{-1}} dr\right), \tag{11}$$

where P_s represents the mean transmission power of the interfering UAVs, and $l(x)$ is the path loss related to the distance. The interference power can be calculated by measuring the mean transmission power of UAVs in the system and computing the integral in (11).

3.2 Performance Analysis of Deterministic Interference

1) Analysis of Self-Interference in New Links: The expression for the deterministic interference component can be represented as

$$I_{k,j}^{d} \triangleq \sum_{i \in \mathcal{R}_j, i \neq k} u_i^m(t) \left| h_{i,j}(t) \right|^2 q_i(t). \tag{12}$$

According to (12), if there exists an m such that $u_i^m = 0$ holds, then for $\forall i \in \mathcal{R}_j, i \neq k$, the deterministic interference component is $I_{k,j}^d = 0$. Therefore, we can draw the following conclusion.

Conclusion 1: If the number of system subcarriers M satisfies $M \geq 2K - 1$, then there exists a subcarrier m that satisfies $I_{k,j}^d = 0$.

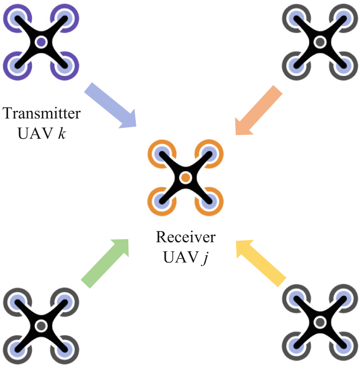

Fig. 1. Schematic diagram of deterministic interference case.

Proof: Fig. 1 illustrates the interference situation in UAV communication, where the different colors of the arrows represent different subcarrier frequency bands. The interference signal received by UAV j comes from the elements in its neighboring UAV set $\mathcal{R}_j$, and the interference power can be expressed as $\sum_{i \in \mathcal{R}_j, i \neq k} u_i^m(t) |h_{i,j}(t)|^2 q_i(t)$. When $u_i(t)^m = 0$, it can be ensured that this communication link is not affected by interference from other UAVs. Since the elements in $\mathcal{R}_j$ can include at most K UAVs, the number of interfering UAVs is at most $K-1$. Considering that UAV k can establish communication connections with at most K UAVs simultaneously, it only needs to ensure $2K-1$ alternative subcarriers on UAV k to ensure that each link is assigned a different subcarrier.

2) Interference Analysis for Existing Links: Similar to the analysis of new links, if there exists an m such that $u_j^m = 0$ holds for $\forall j \in \{x | l \in \mathcal{R}_k, l \neq j, x \in \mathcal{R}_l\}$, then the maximum interference component is

$$\max_{j \in \{x | \in \mathcal{R}_k, l \neq j, x \in \mathcal{R}_7\}} u_j^m |h_{k,j}^m(t)|^2 q_j(t) = 0. \tag{13}$$

Therefore, we can draw the following conclusion.

Conclusion 2: If the number of system subcarriers M satisfies $M \neg K^2$, then there exists a subcarrier m that can satisfy $\max_{j \in \{x | l \in \mathcal{R}_k, l \neq j, x \in \mathcal{R}_\mathcal{R}\}} u_j^m | h_{k,j}^m(t)|^2 q_j(t) = 0$.

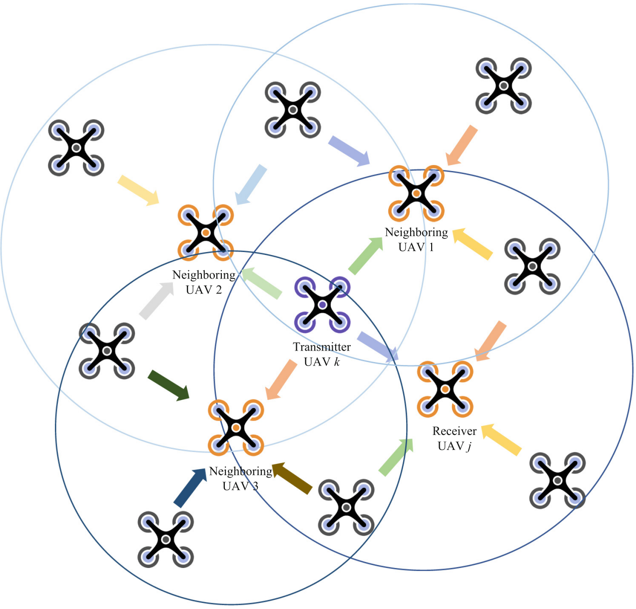

Fig. 2. Schematic diagram of UAV interference in multi-hop transmission mode.

Proof: Fig. 2 illustrates the interference of UAVs on existing links. Unlike Fig. 1, Fig. 2 considers not only the interference of the received signal but also the interference to UAVs within the neighboring range. Since the set of UAVs near the target UAV k includes at most $K - 1$ UAVs, and each of these neighboring UAVs can communicate with at most $K-1$ other UAVs, the number of occupied subcarriers is at most $(K-1)^2$. Additionally, the UAV k can establish communication connections with at most K UAVs simultaneously, so ensuring $(K - 1)^2 + K - 1 + K = K^2$ alternative subcarriers will be sufficient to ensure that no interference is caused to any neighboring UAVs.

3.3 Subcarrier Allocation Scheme

Based on the analysis results of Conclusion 1 and Conclusion 2, we divide the subcarrier allocation problem into three cases.

1) Number of system subcarriers $M \geq K^2$ ***:*** In this case, the UAV k only needs to select unused subcarriers from its neighboring UAVs. In this situation, there is no deterministic interference in the current UAV's communication link, nor does it cause deterministic interference to existing communication links nearby.

2) Number of system subcarriers $K^2 > M \geq 2K-1$ ***:*** In this scenario, the carrier allocation of UAV k scheme only interferes with the original links of other UAVs. The subcarrier allocation optimization problem can be formulated as

$$\min_{m \in \mathcal{A}_k} \left(\max_{j \in \{x | l \in \mathcal{R}_k, l \neq j, x \in \mathcal{R}_l\}} u_j^m \left| h_{k,j}^m(t) \right|^2 q_j(t) \right) \tag{14}$$

Therefore, the optimal solution m^* for this problem satisfies $||h_{k,j}^{m^*}(t)|^2 q_j^m(t)|^2 = \min\limits_{j \in \{x | \in \mathcal{R}_k, l \neq j, x \in \mathcal{R},\}} \{|h_{k,j}^m(t)|^2 q_j^m(t)\}$, i.e., select the same subcarriers as the UAV causing minimal interference among neighboring UAVs.

3) Total number of available system subcarriers $2K-1 > M$***:*** In this case, the subcarrier selection of the UAV needs to jointly consider the interference to itself and the impact on the original communication links. Due to the constraints on the service transmission rate, the transmission power needs to satisfy the constraint of (10).

$$p_k(t) \geq \left(e^{r_k/w} - 1\right) \left(u_i^m \left|h_{i,j}^m(t)\right|^2 q_i^m(t) + \sigma^2\right) / \left|h_{k,j}^m(t)\right|^2. \tag{15}$$

The optimal subcarrier selection result m^* satisfies $\min\limits_{i \in \mathcal{R}_j, i \neq k} \{|h_{i,j}^m(t)|^2 q_j^m(t)\}$. However, this power scheme only meets the transmission rate constraint and may not satisfy the interference constraint on the original links. Therefore, it is necessary to substitute the solved subcarrier allocation result m^* into $\max\limits_{j \in \mathcal{R}_k} u_j^m |h_{k,j}^m|^2 q_j(t)$ to determine whether it satisfies the constraint of not exceeding η_{int}. If the constraint $\mathcal{C}2$ is met, then the solved m^* is the optimal solution to this problem; otherwise, the above allocation result is excluded from the candidate subcarrier set $\mathcal{A}_k$ of the UAV, and the process is executed again.

3.4 Power Optimization Scheme

Since there may be cases where it is impossible to find a subcarrier allocation scheme that meets communication conditions when $M < K^2$, the system should ensure the number of subcarriers $M \geq K^2$ for the sake of system robustness. When interference in the communication link can be effectively eliminated, the power optimization problem can be written as

$$\begin{aligned} &\min_{\{p_k(t)\}_{\forall k \in K} \left\{ \left\{ \{{}^{m}_{k}\}_{\forall k \in K} \right.\right.} \sum_{k \in \mathcal{K}} \int_t p_k(t) dt \\ &\mathcal{C}1 : w \log \left(\frac{\left|h_{k,j}(t)\right|^2 p_k(t)}{I_{k,j}^r + \sigma^2} \right) \geq r_k, \forall k \in \mathcal{K} \end{aligned} \tag{16}$$

Given that the achievable rate $R_{k,j}(t)$ of the communication link increases monotonically with the transmission power $p_k(t)$ of the UAV k, directly calculating the service rate constraint condition can yield the optimal power allocation result. In this case, the optimal power allocation result can be expressed as

$$p_k^*(t) = \frac{\left(e^{r_k/w} - 1\right)\left(I_{k,j}^r + \sigma^2\right)}{\left|h_{k,j}^m(t)\right|^2}. \tag{17}$$

From the results of the power optimization analysis, it can be seen that the minimum transmission power of UAV k is proportional to the interference power. When the density of UAVs λ_u and subcarrier bandwidth W in the network are fixed, increasing the number of neighboring UAVs K can reduce the random interference in the UAV swarms, thereby reducing the total transmission power in the system and improving system energy efficiency.

4 Simulation Analysis

In this section, we verify the effectiveness of the proposed scheme through simulation analysis. This paper considers a swarm of UAVs uniformly distributed over a square area of $5000 \times 5000\,\mathrm{m}^2$, with the number of UAVs set to 100. The total system bandwidth is set to 10 MHz, with 50 available subcarriers. The channel power gain at the reference distance 1 m is $\beta_0 = -60\,\mathrm{dB}$, the pathloss exponent is $\alpha = 2$. The receiver noise power is set to $-109\,\mathrm{dBm}$, and the UAV flight height is set to 100 m. In the energy efficiency analysis, we assume that the minimum communication rate that the UAVs need to achieve is 0.5 Mbps. In the spectral efficiency analysis, we assume that the UAV transmission power is 100 mW, and the number of UAVs that can establish a connection, K, is set to 5.

Figure 3 shows the impact of three different schemes on UAV transmission power under varying numbers of communicable UAVs K. As can be seen from the figure, compared to the random allocation scheme and the scheme that does not consider interference from existing links, the proposed scheme can effectively reduce UAV transmission power and improve energy efficiency as the number of UAVs increases. Specifically, when the number of communicable UAVs K is 7, the proposed scheme achieves nearly 55% and 34% reductions in energy consumption compared to the other two schemes, respectively. This is mainly because the proposed method utilizes the subcarrier allocation information of neighboring UAVs, which can reduce the interference of established links on new links while also reducing interference to existing links. In contrast, the random allocation scheme and the scheme that does not consider interference from existing links maintain high transmission power when the number of communicable UAVs is large. Therefore, the proposed scheme performs better in terms of energy efficiency.

Figure 4 illustrates the impact of three different schemes on spectral efficiency under varying numbers of available subcarriers M. Across the entire examined

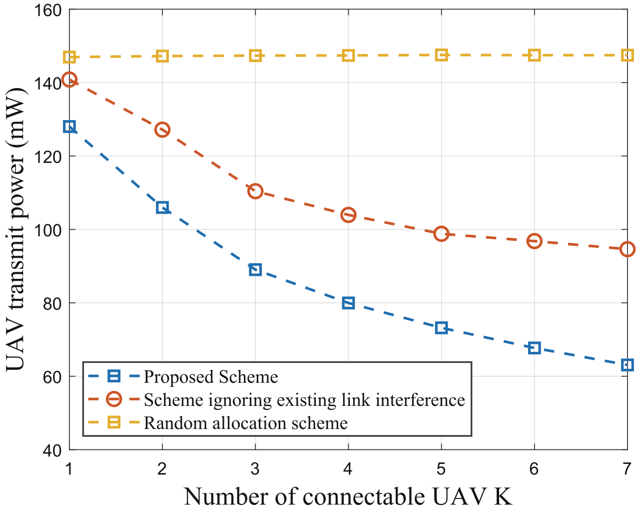

Fig. 3. Comparison of UAV transmission power under different schemes.

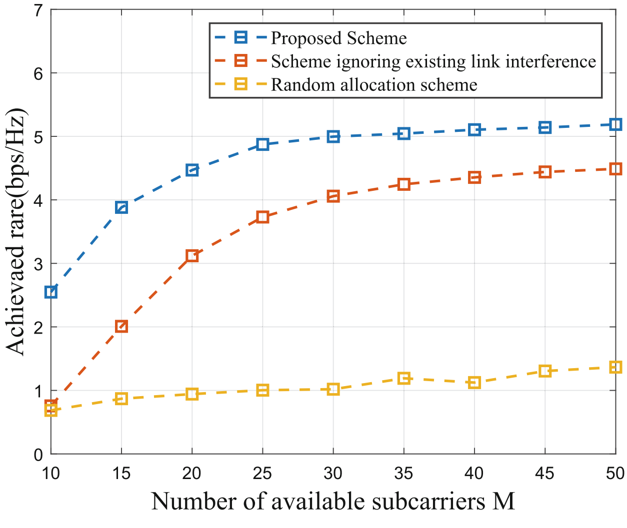

Fig. 4. Comparison of spectral efficiency under different schemes.

range of subcarriers, the proposed scheme significantly outperforms the scheme that does not consider interference from existing links and the random allocation scheme, which is especially true when the number of subcarriers is large, where the spectral efficiency of the proposed scheme is particularly prominent. Specifically, as the number of available subcarriers increases from 10 to 50, the spectral efficiency of the proposed scheme shows a clear upward trend. The increase is primarily due to the expanded selection space for subcarrier allocation with the increase in available subcarriers, thereby enhancing the likelihood of obtaining the optimal allocation scheme. In contrast, the other two schemes fail to effectively utilize all the information in the system, and thus, even under conditions of sufficient subcarrier availability, they do not achieve optimal resource allocation. The lack of effective resource optimization has led to less-than-ideal spectrum efficiency improvements. Therefore, the proposed subcarrier allocation and resource optimization strategy play a significant role in improving spectral efficiency.

5 Conclusion

This study presents an interference management and resource optimization scheme tailored for UAV networks to address interference issues caused by UAV swarms and enhance overall network energy efficiency and spectrum efficiency. The paper introduces a model that distinguishes between deterministic and stochastic interference, devising effective management strategies for each type of interference. Through the proposed subcarrier allocation scheme, deterministic interference is minimized, considering both the demands of establishing new links and minimizing interference to existing links. Additionally, for systems with a large number of carriers, an optimal power allocation strategy is proposed, effectively improving system energy efficiency. Simulation results validate the effectiveness of the proposed approaches; particularly, significant improvements are shown in energy efficiency and throughput performance compared to existing baseline strategies. Simulation results clearly indicate that under different system conditions, such as UAV quantity and number of subcarriers, the proposed approach can significantly reduce UAV transmission power and enhance spectrum efficiency. This research not only provides a new perspective and solution for interference management in UAV networks but also offers theoretical foundations and practical guidance for future UAV network design and optimization.

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