Energy-Efficient Task Allocation for Rotary-Wing Swarm UAV in IoT Networks Using Improved Particle Swarm Optimization

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Abstract: Unmanned Aerial Vehicles (UAVs) are becoming more frequently used in Internet of Things (IoT) settings to gather data, perform surveillance, and conduct monitoring. Nevertheless, the maximum battery capacity onboard is still a significant limitation to rotary-wing swarm UAV operations. Effective task assignment programs are thus needed to increase energy saving and improve mission life. The paper suggests an Improved Particle Swarm Optimization (IPSO) algorithm to use in allocating energy-efficient tasks to swarm UAV networks in rotary-wing swarm networks. The proposed approach also has an adaptive inertia weight mechanism that enhances convergence behavior and helps avoid untimely stagnation. Python is used to create a simulation environment with multiple UAVs and distributed, IoT sensor nodes. The overall energy consumption and convergence rate are used to measure the performance of the proposed IPSO approach. The simulation findings show that the IPSO algorithm has reduced energy consumption and convergence velocity than the traditional PSO, and thus it can be used in energy-conscious UAV swarm tasks in IoT-based applications.

Keywords: Distributed Sensor Networks; Metaheuristic-Based Scheduling; Mission Lifetime Enhancement; Convergence Optimization; SDG 9 Industry, Innovation and Infrastructure

Introduction

Big sensor networks to monitor the environment, to respond to disasters, and to implement smart cities have become possible through the swift development of Internet of Things (IoT) technologies. Rotary-wing Unmanned Aerial Vehicles (UAVs) have become viable infrastructure to gather data of distributed nodes of the IoT because of their flexibility, hovering ability, and mobility. Swarm UAV systems also contribute to the increased efficiency of operations, as they allow the simultaneous operation of different places. Although there are these benefits, energy limitation is one of the most significant challenges in UAV-based IoT networks. The rotary-wing UAVs absorb a lot of energy when flying, hovering, and communicating, and it is important to effectively distribute tasks to extend the operating life. Conventional methods of task distribution tend to be deterministic, and thus they may not yield the best solutions in dynamic contexts. Particle Swarm Optimization (PSO) is a metaheuristic algorithm that has been extensively used to solve UAV path planning and task allocation challenges because of its simplicity and global search. But traditional PSO algorithms have the drawbacks of premature convergence and lack of exploration, which can lead to inefficient distribution of tasks and higher energy use. To meet these issues, this paper presents an Improved Particle Swarm Optimization (IPSO) algorithm with adaptive tuning of inertia weight to efficient assignment of tasks to energy-saving swarm UAVs in rotary-wing networks. The key findings of the paper are; a model of an energy conscious UAV-IoT system has been developed and an adaptive PSO strategy has been introduced to enhance convergence performance and minimize energy consumption.

Related Work

Various works are done on optimization of UAV task allocation and energy management in IoT-assisted environments. Particle Swarm Optimization (PSO) is an optimization algorithm that has received a lot of use due to its efficiency in calculation and the simplicity of implementation. PSO has been shown to be effective in UAV route planning and optimization of path planning problems in the past. However, conventional PSO algorithms tend to prematurely converge particularly when solving a multi node allocation problem. Genetic Algorithms (GA) and Ant Colony Optimization (ACO) are also other metaheuristic methods that have been used to coordinate swarms of UAVs. Such techniques enhance the diversity of searches but might be more computationally complex. Recent research has added adaptive mechanisms in PSO to enhance performance such as dynamic parameter tuning and hybrid optimization strategy. In monitoring systems based on the IoT, energy-conscious UAV deployment has also become a focus. Numerous scholars have suggested energy-efficient routing methods in order to reduce the distance of flight and communication overhead. But few studies have been dedicated to adaptive PSO-based allocation of tasks to rotary-wing swarm UAVs within IoT networks. Thus, lightweight optimization methods that can help to decrease energy usage without sacrificing the convergence speed are still needed.

Proposed Methodology

System Model

The suggested system involves several rotary-wing UAVs that will be deployed to gather data in distributed IoT sensor nodes in a specified area of operation. The main base station organizes the work of UAVs and oversees the implementation of tasks. IoT nodes are randomly spread in a 500 x 500 meters area which is two-dimensional. The UAVs are given a subset of the IoT nodes to collect data.

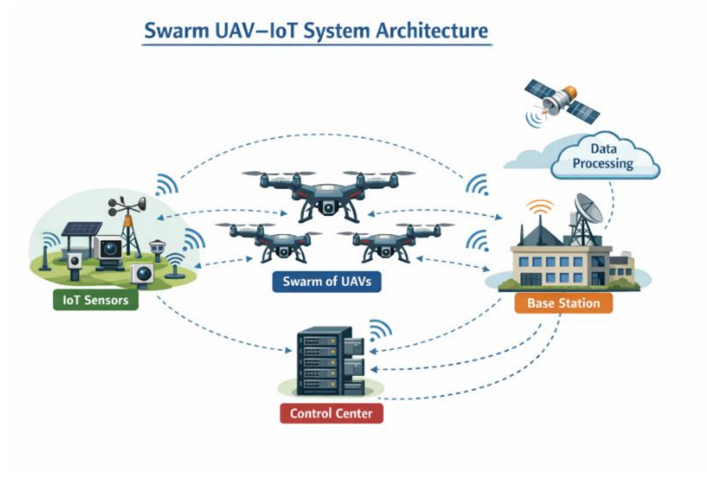

Figure 1. Swarm UAV–IoT System Architecture.

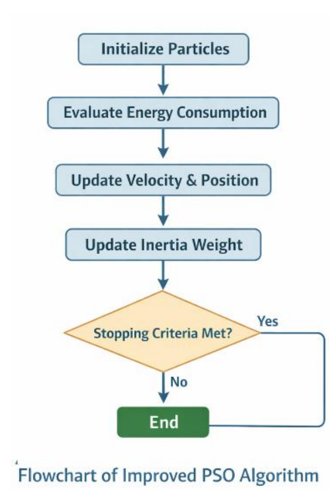

Figure 2. Flowchart of Improved PSO Algorithm

Every UAV is transported between the designated sensor nodes and the overall travel distance directly impacts energy use. So, the allocation of tasks problem is transformed into the problem of energy minimization.

Energy Consumption Model

Flight distance is the main factor that determines the overall energy expenditure of UAVs operations. The objective function can be defined as the overall energy to move UAVs between the points of targets. Total Energy shown in equation (1) as:

$$E_{total} = \sum(d_i \times E_{rate}) \quad (1)$$

Where d_i is distance covered by UAV and E_{rate} is rate of energy used per unit distance. The goal is to decrease overall energy usage and make sure that all the IoT nodes have been approached.

Improved Particle Swarm Optimization

The optimal allocation of tasks to UAVs is determined with the help of Particle Swarm Optimization (PSO). PSO PSO In PSO, every particle can only represent a candidate solution which updates position depending on both personal best solution and global best solution. In order to improve the convergence performance, an adaptive inertia weight mechanism is proposed. The weight of inertia dynamically gets lesser at each iteration thus allowing further exploration in the initial iterations and exploitation in the latter iterations. Adaptive inertia weight is defined by equation (2) as:

$$w = w_{max} - \left((w_{max} - w_{min}) \times iter/iter_{max}\right) \quad (2)$$

Where w_{max} is maximum inertia weight, w_{min} is minimum inertia weight, $iter$ is current iteration and $iter_{max}$ is maximum iteration count. This modification improves search diversity and reduces premature convergence.

Results and Discussion

The implementation of the proposed algorithm is in Python programming language. The simulated environment will be a 500 x 500 meter area with five rotary-wing UAVs and fifty IoT sensor nodes that will be randomly placed. The population size of PSO will be 30 particles with a maximum number of iterations being 100.

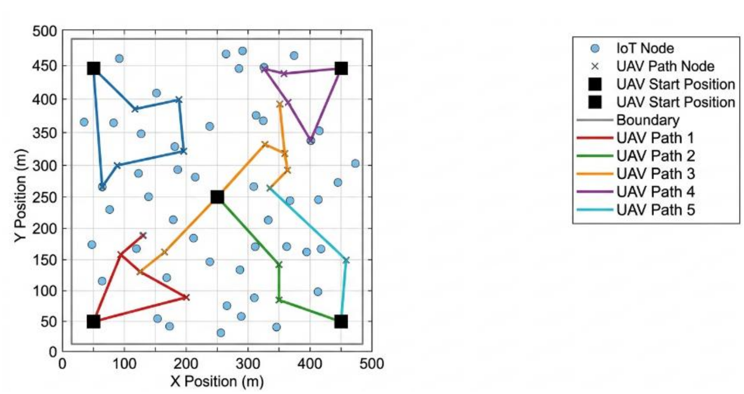

Figure 3. Optimized UAV paths were produced that served five rotary-wing UAVs that served distributed nodes of an IoT in an area of 500 × 500 m.

The result of the Improved PSO (IPSO) algorithm is compared to traditional PSO. The measuring standards are the total energy consumption and the rate of convergence.

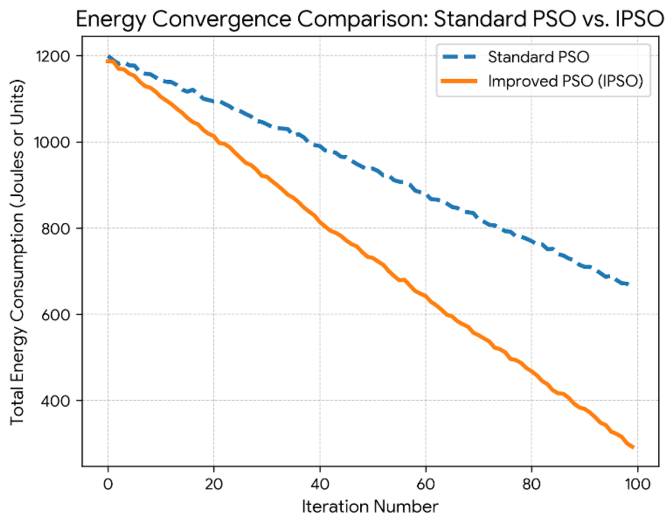

Figure 4. Comparison of the energy convergence between the standard PSO and Improved PSO (IPSO) between 100 iterations with faster convergence and less energy used.

The simulation results have shown that the IPSO algorithm converges faster than regular PSO because of adaptive parameter tuning. The energy consumption curve shows that IPSO has a steadily decreasing energy value at each iteration. The average amount of energy that is consumed using the proposed IPSO method is about 15-20 percent less than the conventional PSO. Moreover, the UAV paths calculated with the help of IPSO demonstrate better task distribution among UAVs, eliminating the redundant flights and the total distance covered by the flights. These findings confirm the hypothesis that adaptive inertia weight enhances the quality of solutions and the efficiency of swarm allocation of UAV tasks.

Conclusion

This paper introduced an Improved Particle Swarm Optimization (IPSO) model of energy-efficient deployment of swarm UAVs in rotary-wing networks in IoT networks. The suggested approach added an adaptive inertia weight mechanism to improve the convergence performance and reduce overall energy usage. The results of simulation showed better energy performance and acceleration of convergence than the standard PSO. The presented IPSO framework offers a simple and efficient approach to UAV swarm optimization. Future research will involve expansion of the model to three dimensional setting and inclusion of dynamic obstacle avoidance to real world application of UAVs.

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