AoI-Minimizing Multi-UAV Trajectories for IoT Data Collection

Minhyuk Kang
Hanyang University
Ansan, Korea
minhyukkang@hanyang.ac.kr

Sang-Woon Jeon
Hanyang University
Ansan, Korea
sangwoonjeon@hanyang.ac.kr

***Abstract*—This paper addresses data collection in multi-UAV–aided IoT networks, focusing on minimizing the average Age of Information (AoI). To overcome the limitations of separate optimization, we propose a joint framework integrating compression-aware aggregation, AoI-optimal node scheduling, and trajectory design. A hybrid genetic algorithm (GA)-ant colony optimization (ACO) method is developed to simultaneously optimize cluster head selection and multi-UAV tours. Simulations demonstrate that the proposed scheme achieves 15 to 25% AoI reduction compared to state-of-the-art benchmarks, validating its robustness across varying network scales.**

***Index Terms*—UAV, age of information, genetic algorithm, ant colony optimization, clustering.**

I. Introduction

Efficient data collection from large-scale IoT networks is challenging [1]. UAVs provide flexible mobile collection [2], but direct-visit strategies scale poorly. Cluster-based designs with compression-aware aggregation improve scalability [3], [4]. Age of Information (AoI), defined as the time elapsed since the most recent data update, is key for time-sensitive applications [5]. Existing schemes do not jointly optimize cluster head (CH) selection, aggregation, and multi-UAV trajectories. This paper proposes such a framework using hybrid GA-ACO.

II. System Model and Proposed Hybrid GA-ACO

We consider N IoT nodes and L UAVs operating at altitude z_{uav} with speed v_{uav}. Nodes are partitioned into M clusters with CHs $\mathcal{H} = \{h_1, \dots, h_M\}$. Each node generates β bits. The data rate over distance d is $R(d) = W \log_2(1+P/(WN_0 d^{\gamma}))$. Transmission time from node n to its CH is $\tau_{\text{trans}}(n) = \beta/R(d_{n,m})$. The aggregated data size at CH h_m is $B_m = \beta(1-(1-\alpha)^{|\mathcal{N}_m|})/\alpha$, where α is the compression factor. The AoI of node n is $\text{AoI}(n) = \max_l T_{\text{mission},l} - T_{\text{gen}}(n)$, where $T_{\text{mission},l}$ is UAV l's mission time and $T_{\text{gen}}(n)$ is generation time. Average AoI is minimized when intra-cluster transmissions are scheduled in nonincreasing order of transmission time.

The proposed hybrid GA-ACO jointly optimizes CH selection and trajectories. Each GA chromosome represents a CH set. For each candidate, CHs are assigned to nearest UAV depots, and ACO constructs tours by solving traveling salesman problems. Nodes transmit in nonincreasing order of transmission time, yielding average AoI as fitness. Tournament selection, crossover, mutation, and elitism evolve the population.

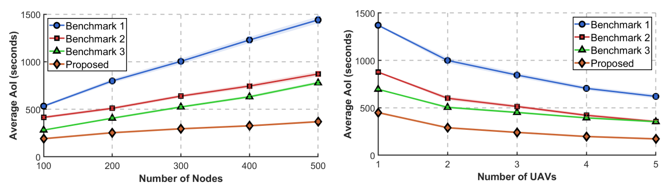

Fig. 1: Average AoI vs N (left) and L (right) at $v_{\text{uav}} = 15$ m/s, $\beta = 5$ Mbits.

III. Numerical Results

Simulations use 100 to 500 nodes in 1.5×1.5 km^2, 1 to 5 UAVs at 100 m altitude and 15 m/s speed, 15 clusters, 5 Mbits data, 100 kHz bandwidth, and 0.05 compression. GA uses population size 20 and 30 generations, while ACO uses 12 ants and 30 iterations. Benchmarks include direct visit, center hovering, and ACO-based aggregation.

Fig. 1 shows average AoI versus N (left) and L (right). The proposed scheme significantly reduces AoI by optimizing CH locations to minimize flight distance. Performance gain increases with network size, demonstrating scalability. Increasing UAVs reduces AoI for all schemes, but the proposed approach consistently outperforms benchmarks.

Acknowledgment

This work was supported by NRF grant (No. RS-2024-00336983). S.-W. Jeon is the corresponding author.

References

[1] D. C. Nguyen, M. Ding, P. N. Pathirana, A. Seneviratne, J. Li, D. Niyato, O. Dobre, and H. V. Poor, "6G Internet of Things: A comprehensive survey," *IEEE Internet Things J.*, vol. 9, no. 1, pp. 359–383, Jan. 2022.

[2] M. Mozaffari, W. Saad, M. Bennis, Y.-H. Nam, and M. Debbah, "A tutorial on UAVs for wireless networks: Applications, challenges, and open problems," *IEEE Commun. Surv. Tutor.*, vol. 21, no. 3, pp. 2334–2360, Thirdquater 2019.

[3] M. Kang and S.-W. Jeon, "Energy-efficient data aggregation and collection for multi-UAV-enabled IoT networks," *IEEE Wireless Commun. Lett.*, vol. 13, no. 4, pp. 1004–1008, Apr. 2024.

[4] Y. Bai, P.-F. Sun, T.-H. Wang, B. Sun, W.-J. Yu, J.-H. Zhong, G.-H. Song, S.-W. Jeon, S. Kwong, and J. Zhang, "UAV path planning for data collection from wireless sensor network with matrix-based evolutionary computation," *IEEE Trans. Intell. Transp. Syst.*, vol. 26, no. 9, pp. 13 672–13 687, Sep. 2025.

[5] R. D. Yates, Y. Sun, D. R. Brown, S. K. Kaul, E. Modiano, and S. Ulukus, "Age of Information: An introduction and survey," *IEEE J. Sel. Areas Commun.*, vol. 39, no. 5, pp. 1183–1210, May 2021.