Charging-Constrained Decentralized Task Allocation for Persistent Multi-UAV Construction Monitoring

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***Abstract*— Persistent multi-UAV construction monitoring requires task assignments that account for limited onboard energy, access to shared charging resources, and monitoring priority. This paper proposes a decentralized task-allocation method based on the Consensus-Based Bundle Algorithm (CBBA) that incorporates route-level battery feasibility and charger availability within bundle construction and consensus while retaining priority-aware task scoring. The method excludes battery-infeasible task insertions, coordinates charger reservations during consensus, and shifts reservations or releases tasks when charging conflicts cannot otherwise be resolved. A 120-min Webots study with four UAVs, eight recurring safety and quality tasks, and one charger was used for evaluation. Across the mission, the proposed method coordinated recurring monitoring tasks while maintaining the prescribed 15% battery reserve, with a minimum state of charge of 18.34%, and completing 71 task services. A comparison with a baseline CBBA that applied the same battery-feasibility constraint but did not coordinate charger access showed that the proposed method reduced charger conflicts from 3 to 0, cumulative lateness from 3489.0 s to 2002.8 s, and increased completed services from 68 to 71. The results indicate that jointly accounting for battery feasibility, shared-charger availability, and task priority could improve the continuity and energy reliability of persistent multi-UAV construction monitoring.**

I. INTRODUCTION

Unmanned aerial vehicles (UAVs) are increasingly used on construction sites for progress documentation, inspection, and safety assessment. Most current applications rely on individually planned flights conducted at scheduled intervals. This operating model is generally suitable for progress monitoring, where periodic observations can document changes over days or weeks. Safety monitoring and time-sensitive inspection present a different requirement because hazardous conditions, equipment interactions, and active work zones can change within much shorter periods. The intervals between scheduled flights therefore leave important site conditions unobserved when timely awareness is most needed. More continuous aerial observation could reduce these gaps and support earlier detection of conditions requiring inspection or intervention.

A team of UAVs can observe several areas concurrently and distribute monitoring responsibilities across the construction site. Sustaining this coverage over extended periods remains difficult because each UAV must periodically leave its assigned tasks to recharge. The remaining UAVs must accommodate the resulting reduction in available monitoring capacity, while UAVs requiring recharge must obtain access to a limited number of charging stations. Task allocation and charging decisions are therefore coupled. An allocation that is efficient in terms of travel distance may be infeasible when the battery energy required to complete the assigned route and reach a charging station is considered. Similarly, independent charging decisions can result in simultaneous demand for the same station and interruptions in site coverage.

Multi-robot task allocation has been studied extensively using centralized optimization, market-based methods, and decentralized coordination. The Consensus-Based Auction Algorithm (CBAA) and Consensus-Based Bundle Algorithm (CBBA) provide conflict-free task assignments through local bidding and communication between agents [1]. CBBA allows each agent to construct an ordered bundle of tasks and has subsequently been extended to asynchronous communication, dynamic task arrival, partial replanning, and local replanning [2]–[4]. More recent variants improve scalability and load balancing for large or heterogeneous UAV teams [5]. These methods provide a well-established basis for decentralized coordination, although their standard formulations do not explicitly account for the recurring charging requirements of persistent construction monitoring.

Energy-constrained persistent monitoring has been considered through latency-aware routing, mobile charging stations, robot rendezvous planning, and long-term charging schedules [6]–[9]. Recent distributed approaches also incorporate battery limitations into monitoring-task selection and enable unattended monitoring locations to be redistributed among available UAVs [10]. However, these approaches generally treat access to the charging resource separately from decentralized task allocation. Conversely, shared-charger scheduling methods can explicitly prevent simultaneous charger use, but operate as a separate scheduling layer given nominal mission trajectories rather than allowing charger availability to directly influence task assignment [9]. Research on UAV energy consumption further provides detailed models relating battery use to vehicle dynamics, flight direction, payload, and operating conditions [11], [12]. Such models are valuable for accurate mission prediction, although their complexity is not always necessary for task-level allocation over a limited planning horizon.

This paper proposes a charging-constrained decentralized task-allocation method for persistent multi-UAV construction monitoring. The method employs CBBA while incorporating the priority of each construction-monitoring task, the additional travel required by its insertion into a UAV route, and the battery energy needed to complete the route and reach

The authors would like to acknowledge financial support from ND EPSCoR for this research.

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a charging station. Charging opportunities are treated as limited shared resources within the allocation process, allowing charger availability to directly influence task bidding, retention, and reassignment. Infeasible task insertions are excluded before bidding, ensuring that the resulting task bundles preserve sufficient energy for the UAVs to recharge safely while respecting shared-charger availability.

The principal contribution is a charging-constrained CBBA formulation that couples decentralized task allocation with limited charger availability. The formulation retains the decentralized bundle construction and consensus mechanism of CBBA while incorporating task priority and battery feasibility and introducing charging-station availability as a shared allocation constraint. A Webots simulation study examines the resulting allocation and charging behavior using multiple UAVs, construction-related safety and quality tasks, and a limited shared charging resource.

II. Methodology

A. Problem Formulation

Consider a team of N UAVs, $I = \{1, \dots, N\}$, assigned to a set of construction-monitoring tasks $J = \{1, \dots, M\}$. Each task $j \in J$ is defined by its location, priority w_j, service duration d_j, and required revisit interval. Completed tasks are released again according to their revisit requirements to support persistent monitoring. Each UAV $i \in I$ maintains its current position, remaining battery energy B_i, and an ordered bundle of assigned tasks.

The UAVs share a single charging station that can accommodate only one UAV at a time. A UAV must therefore preserve sufficient energy to complete its assigned route and reach the charging station. For a candidate path p_i, energy feasibility is imposed as

$$E_i^{\text{route}}(p_i) + E_i^{\text{return}}(p_i) + E_i^{\text{reserve}} \leq B_i \tag{1}$$

where E_i^{route} includes the energy required for travel and task execution, E_i^{return} is the energy required to travel from the final task to the charging station, and E_i^{reserve} is a prescribed safety reserve. Energy is therefore treated as a feasibility constraint rather than as an additional weighted component of the allocation score.

The charging station is modeled as an exclusive shared resource. Battery replenishment is abstracted as instantaneous in this study so that long charging durations do not dominate the coordination problem, since realistic charging times with a single shared charger could otherwise make sustained operation of the UAV team infeasible. Each charging event instead occupies the station for an access interval τ_c, representing the landing, docking, and departure process.

B. Priority- and Energy-Aware Bundle Construction

The proposed method employs the standard CBBA bundle construction and consensus framework [1]. Each UAV greedily constructs an ordered path by evaluating the marginal benefit of inserting an available task at different positions in its current path. The score of a candidate path is defined as

$$S_i(p_i) = \sum_{j \in p_i} w_j \, e^{-\lambda C_{ij}} \tag{2}$$

where C_{ij} is the predicted completion time of task j along path p_i, including both travel time and task service duration, and λ controls the effect of delayed completion. A value of 0.05 min^{-1} was used for both methods, providing a moderate discount for delayed completion. The term w_j represents the priority weight assigned to task j. Higher-priority tasks therefore provide greater reward, while tasks completed later in the route receive a reduced contribution.

The marginal bid of UAV i for task j is

$$c_{ij} = \max_n [S_i(p_i \oplus_n j) - S_i(p_i)] \tag{3}$$

where $p_i \oplus_n j$ denotes insertion of task j at position n. An insertion is considered only when the resulting route satisfies the energy-feasibility constraint. The normal CBBA winner and bid vectors are then exchanged among UAVs to resolve conflicting task assignments.

C. Charging-Constrained Allocation

For every feasible candidate bundle, UAV i predicts its arrival time at the charging station after completing the assigned tasks,

$$t_i^c = t + T_i^{\text{route}}(p_i) + T_i^{\text{return}}(p_i) \tag{4}$$

where t is the current allocation time. The corresponding charger reservation is

$$R_i = [t_i^c, t_i^c + \tau_c) \tag{5}$$

Because the charger has a single UAV capacity, reservations of different UAVs must satisfy

$$R_i \cap R_k = \emptyset, \quad \forall i, k \in I, i \neq k \tag{6}$$

Charger availability is evaluated during bundle construction together with energy feasibility. UAVs exchange their predicted charging intervals together with the normal CBBA allocation information. When two proposed reservations overlap, priority is given to the UAV with the smaller remaining energy margin,

$$m_i = B_i - (E_i^{\text{route}} + E_i^{\text{return}} + E_i^{\text{reserve}}) \tag{7}$$

The UAV with the smaller m_i retains the charging reservation because it has less flexibility to continue operating before recharge. Agent identifiers are used to resolve ties. The UAV that loses the charging conflict first searches for a later nonconflicting interval that remains energy feasible. If no feasible charging interval is available, tasks are removed from the end of its bundle until both route and charger feasibility are restored. The released tasks return to the available task set and can subsequently be acquired by other UAVs through the normal CBBA bidding process. Consequently, a charging conflict can directly trigger bundle modification and subsequent task reassignment.

Bundle construction and consensus are repeated until no task-assignment or charging-reservation conflicts remain. This coupling distinguishes the proposed method from approaches in which charging is coordinated only after the monitoring trajectories or task assignments have already been determined.

III. Simulation Study

A. Simulation Setup

The proposed method was evaluated in Webots R2025a using a simulated construction site containing a two-story reinforced-concrete structure, active work areas, construction materials, and site equipment, as shown in Fig. 1. Four Mavic 2 Pro UAVs monitored eight recurring tasks distributed across the site. Four safety-monitoring tasks had priority 2, a 600-s revisit interval, and a 300-s service duration, while four quality-inspection tasks had priority 1, a 1200-s revisit interval, and the same 300-s service duration. A single charging station was available to the UAV team.

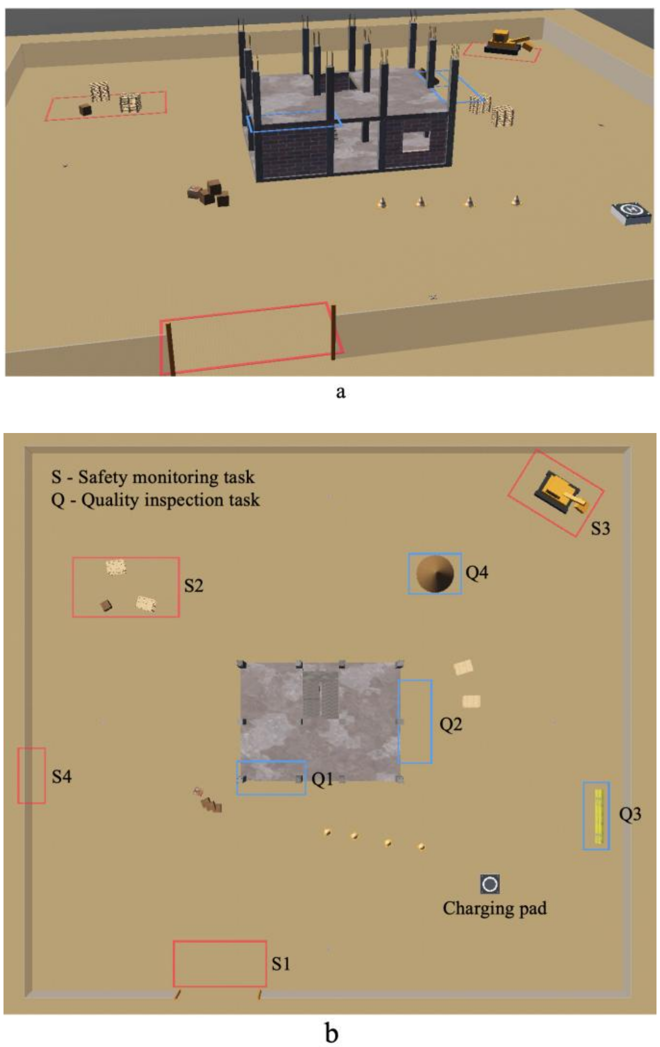

Fig. 1. Webots simulation environment for persistent multi-UAV construction monitoring: (a) construction site environment and (b) plan view showing monitoring tasks and the shared charging station.

Each UAV was modeled with a battery capacity of 213,444 J and a nominal power consumption of 120 W, corresponding to approximately 29.6 min of continuous operation. A cruise speed of 4 m/s and a 15% battery reserve were used for route-feasibility evaluation. All UAVs began fully charged. Battery replenishment at the charging station was instantaneous, while each charging event reserved the station for 30 s to represent landing, docking, and departure. All UAVs communicated over a shared simulated channel and exchanged task-allocation and charger-reservation information.

B. Evaluation Design

The proposed charging-constrained CBBA was evaluated using the same task score, service durations, battery model, and battery-feasibility constraint throughout the study. For comparison, a baseline CBBA used the same battery-feasibility constraint but did not consider charger availability during task allocation. Consequently, multiple UAVs could independently plan overlapping returns to the single charger. During execution, however, only one UAV was permitted to occupy the charger. A UAV arriving while the charger was occupied remained airborne nearby and continued consuming the nominal flight power until access became available. The proposed method instead considered charger availability during allocation and modified affected bundles when required.

Each method was evaluated over a 120-min persistent-monitoring mission under identical initial conditions. Tasks were released 15 s before their revisit deadlines to allow time for bidding and travel so that a UAV could begin service by the required revisit time. A revisit violation was recorded when service began after the required revisit time. The recorded measures were charger conflicts, revisit violations, cumulative lateness, completed safety and quality services, total services, and minimum state of charge.

IV. Results and Discussion

The proposed method completed the 120-min mission with no charger conflicts, maintaining nonoverlapping access to the single charging station, as shown in Fig. 2. For comparison, the baseline produced three charger conflicts because overlapping returns were not resolved during allocation.

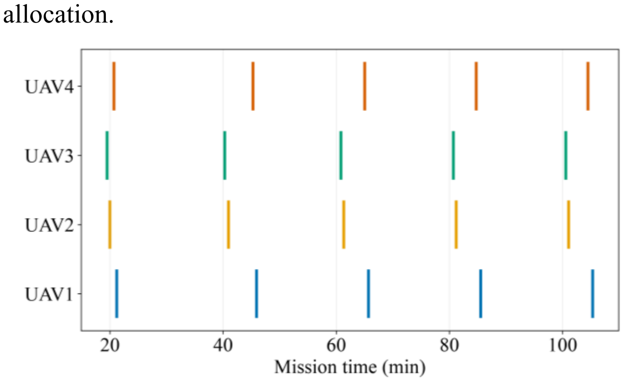

Fig. 2. Charger-access timeline for the four UAVs during the 120-min mission using the proposed method.

The proposed method incurred 12 revisit violations and 2002.8 s of cumulative lateness during the mission. The baseline incurred 14 revisit violations and 3489.0 s of cumulative lateness. Fig. 3 shows the number of overdue tasks over the mission.

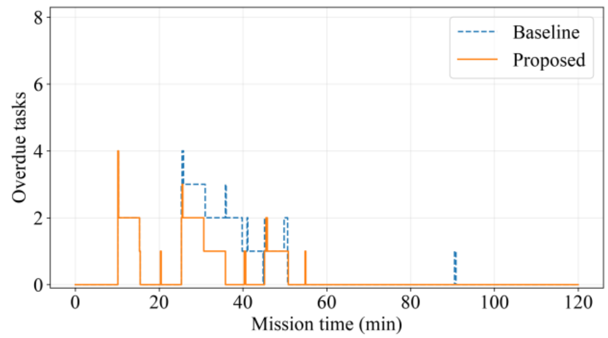

Fig. 3. Number of monitoring tasks exceeding their required revisit intervals during the 120-min mission for the baseline and proposed method.

The proposed method completed 48 safety and 23 quality services, for a total of 71 completed services. The baseline completed 46 safety and 22 quality services, for a total of 68. The overall performance comparison is summarized in Table I.

TABLE I. Performance comparison of task-allocation methods.

Metric	Baseline	Proposed method
Charger conflicts	3	0
Revisit violations	14	12
Cumulative lateness (s)	3489.0	2002.8
Safety services	46	48
Quality services	22	23
Total services	68	71
Minimum SoC (%)	13.62	18.34

The proposed method maintained a minimum state of charge of 18.34%, remaining above the prescribed 15% reserve. The baseline reached a minimum state of charge of 13.62%. Although both approaches applied the same route-level battery-feasibility constraint, unplanned charger contention in the baseline could consume energy beyond the planned route margin.

Overall, in the evaluated scenario, the proposed method effectively coordinated recurring monitoring tasks while maintaining battery feasibility and shared-charger access. The comparison indicates that incorporating charger availability prevented conflicts, reduced monitoring lateness, and increased completed services.

V. Conclusion

This paper presented a decentralized CBBA-based method for persistent multi-UAV construction monitoring that jointly considers battery feasibility, shared-charger availability, and monitoring priority. Battery feasibility is enforced during bundle construction, while charger reservations are coordinated during consensus, with task reassignment when conflicts cannot be resolved through reservation shifting. In the 120-min Webots study, the method maintained the prescribed battery reserve and completed 71 safety and quality services. Compared with a baseline CBBA using battery feasibility but not charger coordination, it eliminated three charger conflicts, reduced cumulative lateness from 3489.0 s to 2002.8 s, and completed three additional services. These results suggest that incorporating battery and shared-charging constraints directly into decentralized allocation could support more reliable persistent construction monitoring. The evaluation was limited to a single deterministic simulation configuration and baseline and used instantaneous battery replenishment, a constant-power energy model, and ideal communication. Future work will therefore evaluate broader configurations and comparison methods, finite-duration charging and detailed energy models, communication uncertainty, convergence behavior, and physical UAV experiments.

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