Unmanned Aerial Vehicles (UAVs): Persistent Surveillance for a Military Scenario

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***Abstract*— Due to their capabilities for observation, unmanned aerial vehicles (UAVs) have proven themselves beneficial to the varying field operations of the armed forces and similar civilian operations. This study defines two different designs of persistent surveillance mission: hands-off and rendezvous. In the hands-off, the low-fueled UAVs hand off the mission tasks to fully-fueled replacement UAVs. The low-fueled UAVs then return to the base for battery charge. After being recharged, they navigate to other missions to keep the rotation. On the other hand, in the rendezvous, the low-fueled UAVs stay at surveillance locations and mobile charging stations seek rendezvous with the UAVs before batteries drain. The mobile charging stations mutually calculate a set of tours to locate, join and refuel all UAVs in the midst of ongoing projects. The objective is to allow the UAVs to remain on their missions without returning to the base for battery replenishment. As a result, the UAV time in maintenance repose is lowered and mission extension options can be better managed.**

NOMENCLATURE

γ_{ij}	travel-time of UAV between job i and j
c	UAV endurance time in minutes
f	number of flying charging stations (F)
h	planning horizon
i_v	initial mission completion time of UAV v
k	number of parallel UAVs ($k = p + n$)
M	arbitrarily large number (10^4)
n	number of surveillance locations
p	number of spare UAVs
r	battery replacement/recharging time

I. INTRODUCTION

Over the last 10 years, accounting for 90 percent of their market [1], the deployment of unmanned aerial vehicles (UAVs) has become a pivotal piece of military strategies. These mobile robots have applications for observation used toward persistent surveillance and site monitoring activities in addition to civilian applications. During persistent surveillance, the UAV is positioned in a specific location, with little

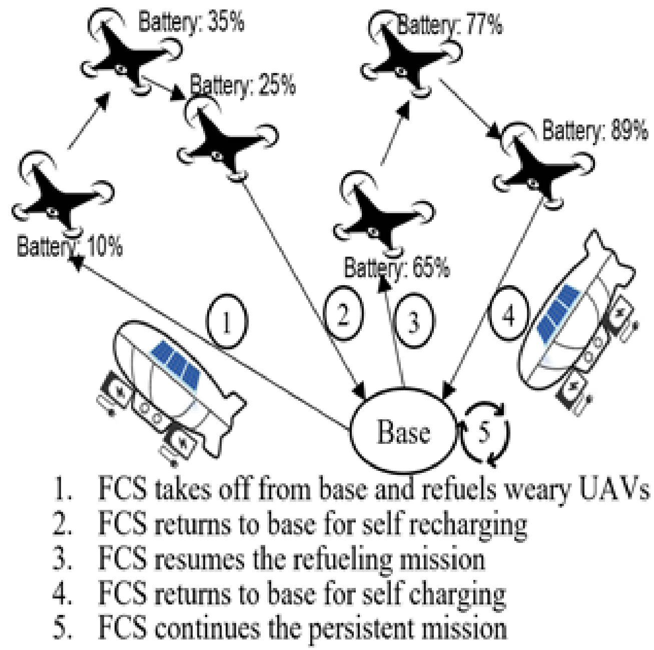

Fig. 1: The proposed UAV coalition formation and routing problem with temporal/special, synchronization, and battery constraints.

to no movement, to observe its target [2]. This type of set up permits the UAV to capture causes to immediate changes in activity in their location. These capabilities that UAVs hold are deemed useful in missions involving transportation control [3], environmental analysis [4], and human interaction [5], where continuous updates are necessary for process improvement and safety. In placing UAVs to assess these potentially dangerous missions, they have spared the lives of countless soldiers and have saved the armed forces in millions of dollars on in-person equipment and training [2].

However, no matter the model of UAV, the consumption of the device's energy supply is a major constraint (Achilles' heel) to persistent surveillance missions. Previously, as mentioned in [6]–[10], when the energy supply ran low, recharging could only be met by two requirements: the UAV returning to its base and human interaction for charging purposes. When the UAV had replenished, it would be set to journey back to its post, which consumed energy, and resumed the cycle with what energy remained. Luckily, technological advancement and recent studies such as [1],

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[2], [11]–[13] have made strides in autonomizing the replenishment process by means of machine learning so the systems of the UAV may realize the need to recharge. The matter at hand is how, of the research cited in this case, the projects were designed. Typically, the focus was to be effective in the aspect of either a largely forged hands-off or a well-crafted rendezvous design.

Our research compares both hands-off and rendezvous designs for UAV persistent surveillance as well as presents a uniquely framed model using the rendezvous method. Hands-off consists of the UAVs taking off, independently, to follow pre-determined routes as planned on a scheduled timetable to reach the charging station. Whereas rendezvous is the sequential or simultaneous arrival of the UAVs and the mobile charging stations to the appointed position. Of the several UAV models that the U.S. armed force employs, the quadcopter is the one that will be used for this research. A quadcopter is raised and steered by four rotors that permit nimbleness in movement [4]. Our rendezvous simulation is inspired by [14] where Unmanned Surface Vehicles, acting as mobile chargers, support Autonomous Underwater Vehicles in mapping applications.

In that same regard, we introduced a team of support UAVs, in the form of blimps, for rendezvous to serve as flying charging stations (UAV-FCSs) as depicted in Figure 1. Furthermore, the graph structure in [15] influenced the path planning for our rendezvous with its patrol operations network. The UAV-FCSs distanced an adjusted path to rendezvous with field UAVs within proximity of their post because they are expected to recharge multiple field UAVs in addition to journeying back to base for their own replenishment. The structure of the paper is as follows: a literature review is briefly presented in Section II. Then, in Section III, the problem descriptions and formal mathematical models for both case designs are explained. Next, in Section IV, there is the computational experiments. To finish, we conclude our results, insights, and future considerations.

II. Literature Review

Autonomizing menial tasks for the sake of efficiency has become the way of the future in various corporations globally. It is of no surprise that this type of innovation would be sought after by UAV users. There is countless research, both former and ongoing, that has autonomized the recharging process of UAVs. In the instances of [12] and [16], they constructed groundbreaking designs that replaced the physical batteries of a UAV, hybrid battery charging systems and pathways. However, their designs would still maintain a time lapse between the UAVs.

As it applies to our research, a hands-off (autonomous) approach is still considered a fresh perspective in UAV energy replenishment studies. It is likely due to the complications in determining the computational aspects for both routing and scheduling the UAVs for real world testing. Although it is cited in limited pieces of literature. In [15], the authors developed a spatial network for unmanned submarines from nodes linked by edges. Next, Erdelj *et al.* created a virtual uninterrupted UAV service, to be offered to the user, composed of exchangeable UAVs that run a continuity-of-service algorithm [17]. Continuing, Hartuv *et al.* explained an offline case where spare UAVs are used at the utmost minimal number for replacement [18]. Lastly, Song *et al.* formed a mixed integer linear program meant to improve scheduling process for UAV self-direction [19]. All of these cases possess potential in their respective rights; however, the researchers assumed an unlimited energy capacity of chargers, their work proceeds without mention of such limitations for switching the UAVs. Furthermore, these studies do not reveal their benchmarked test instances, nor do they share their procedures for meeting optimality.

For the option of rotation swarms, Hassija *et al.* proposed a distributed network that the UAV and the charging station would join to exchange information, such as distance from the station or cost of refill, for energy trading [8]. Our approach would have a similar tactic between the field posted UAV and that of the one parked at the charging station. The field posted UAV sends its health information to the parked UAV to initiate the rotation cycle. In [8], security maintenance may become a conflict of interest because the network is detectable and accessible by other UAVs. We would differ by having a private network with layered encryption methods for our defense, however, the network may still face conflict down the line.

The contributions of this paper are as follows: (i) a set of benchmarking test instances is provided, (ii) optimality of the small-scale test instances is provided, (iii) a comparison study between two designs is conducted, and (iv) how chargers should also recharge themselves after replenishing multiple UAVs is studied, all for the first time.

III. Problems Descriptions

A. Hands-off Design

Let L represent the set of locations $\{1, ..., n\}$ where n denotes the number of surveillance locations. Then let V represent the set of UAVs $\{1, ..., k\}$, where k denotes numbers of parallel UAVs. The persistent UAV scheduling can be defined on a directed graph $G = (N, A)$, $N = L \cup b$, where b represents the base and A is the set of arcs. For each arc $(i, j) \in A$, the time required for the UAV to travel between nodes is given by t_{ij}. For each surveillance location, one UAV must be always present. The UAVs have limited energy, thus they must be recharged or replaced before their batteries drain.

In the hands-off design, the low-fueled UAVs hand off the mission tasks to fully-fueled replacement UAVs. Moreover, when replaced, they must have enough energy to return to the base for battery charge. After they have been recharged, they navigate to other surveillance locations to keep the rotation. The required number of UAVs necessary to ensure persistent surveillance is greater than n. We refer to the p spare UAVs, that is, the UAVs used for replacing other UAVs. The goal is to minimize the number of spare UAVs [15], [18]. At the beginning of planning, each surveillance location is assumed to be serviced by UAV v with remaining endurance time (i_v).

A detailed timetable schedule for each location can be generated as follows. Let $T_{j,t}$ represent the set of discrete tasks associated with location j, where its end-time is equal to start-time of $T_{j,t+1}$ to ensure a continuous coverage. The end-time of $T_{j,t+1}$ is equal to sum of the start-time of $T_{j,t}$ and $c - 2\gamma_{b,j}$ to compensate the round flight between the base, b, and surveillance location, j. Each surveillance task is followed by its linked charging task, $C_{j,t}$, where the start-time of $C_{j,t}$ is equal to sum of the end-time of $T_{j,t}$ and $\gamma_{j,b}$. The end-time of $C_{j,t}$ is equal to sum of the start-time of $C_{j,t}$ and r. The start and end times are termed s and e, respectively. The proposed constraint programming (CP) model for hands-off design is built upon the following decision variables:

$$\min \sum_{v \in V} Z_v \tag{1}$$

$$\text{s.t. } alternative(Tsk_t, [Tsk2V_{t,v}]_{v \in V, t \in T \cup C}) \tag{2}$$

$$presence(Tsk2V_{t,v}) = presence(Tsk2V_{c,v}) \quad \forall v \in V, t \in T, c \in C \tag{3}$$

$$noOverlap(SeqVeh_v, \gamma), \forall v \in V \tag{4}$$

$$noOverlap(SeqLoc_j), \forall j \in L \tag{5}$$

$$Z_v \geq Z_{v+1} \tag{6}$$

$$Z_v \geq presence(Tsk2V_{t,v}) \tag{7}$$

where:

Z_v	1 if UAV v is used; 0 otherwise
Tsk_t	interval representing the t-th task ($t \in T \cup C$)
$Tsk2V_{t,v}$	optional interval representing the j-th task by UAV v
$SeqVeh_v$	collection of intervals ($Tsk2V$) assigned to UAV v where each vehicle is initially located at i_v
$SeqLoc_j$	collection of intervals (Tsk) assigned to location j

The objective (1) is to minimize the number of UAVs used. Note the function does not consider the travel distance since each UAV navigates over a predetermined route between the base and surveillance locations. Constraint (2) ensures that each task is served exactly once by one of UAVs. Constraint (3) guarantees that each surveillance task is immediately followed by its linked charging task. Constraint (4) ensures the travel time between the base and surveillance locations. The expression noOverlap (s, γ) defines a chain of non-overlapping intervals, and any interval in the chain is constrained to end before the start of the next interval in the chain. The transition distance matrix γ defines the minimal distance that must separate two consecutive intervals in the sequence. Constraint (5) is a redundant constraint to assure there is only one UAV at each surveillance location. Constraint (6) breaks a symmetry and uses UAVs in order. Constraint (7) determines whether each UAV is used.

Figure 2 represents an optimal schedule of sample benchmark instance according to Hands-Off design. The upper area shows the detailed task schedule per UAV and the lower depicts how each surveillance location is fully covered by consecutive UAVs visits. At 137, UAV 1, which was initially servicing location 1, fuel becomes low and navigates to the base for recharge while handing the task off to UAV 4. After being recharged, UAV 1 begins service at location 2 (handing off with UAV 6) between 227 and 417. UAV 1 fuel again is low so it navigates to the base while handing the task off to UAV 4, for persistent surveillance. The same UAV covers location 1 between 537 and 720. Note travel times between the base and surveillance locations are considered.

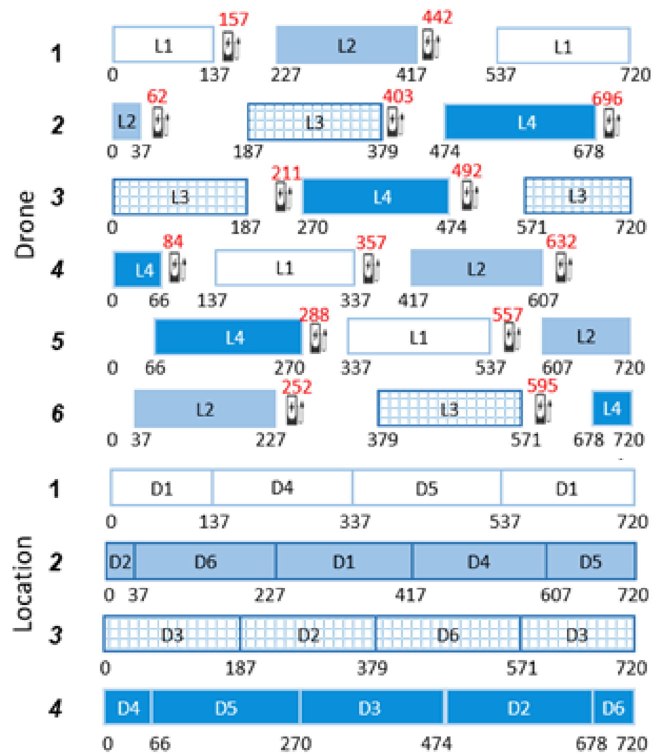

Fig. 2: Schedule of the sample instance according to hands-off design.

B. Rendezvous Design

In this design, the low-fuel UAVs stay at surveillance locations and FCS seeks rendezvous with the low-fuel UAVs before batteries drain. Within the pre-calculated time windows, FCSs must repeatedly visit each UAV for recharging during the entire planning horizon. The objective is to minimize the number of FCSs used and total traveling distance. This design can be represented by the well-known vehicle routing problem (VRP).

1) Mixed Integer Programming: The problem can be defined on a directed graph $G = (N, A)$, where N is the set of nodes and A is the set of arcs. Here, N is defined as $N = C \cup \{\overrightarrow{b}, \overleftarrow{b}\}$, where nodes $\overrightarrow{b}$ and $\overleftarrow{b}$ represent, respectively, the origin and destination bases. Furthermore, a routing cost c_{ij} and a travel time γ_{ij} are associated with each arc $(i, j) \in A$. And we add the penalty value M to the cost of each arc that leaves the initial base to minimize the number of FCSs used, similar technique used by [20]. The formal mathematical model for rendezvous design is built upon the following decision variables:

$B_{v,t}$ the time at which FCS v begins task t
$X_{v,t,\hat{t}}$ 1 if FCS v travels from task t to $\hat{t}$

The original MIP formulation provided by [20] is modified to represent the rendezvous design.

$$\min \sum_{v\in F}\sum_{t,\hat{t}\in C} X_{v,t,\hat{t}} \cdot C_{t,\hat{t}} \tag{8}$$

$$\text{s.t.} \sum_{v\in F}\sum_{\hat{t}\in C} X_{v,t,\hat{t}} = 1, \forall t \in C \tag{9}$$

$$\sum_{\hat{t}\in C} X_{v,\hat{t},t} = \sum_{\hat{t}\in C} X_{v,t,\hat{t}}, \forall t \in C, v \in F \tag{10}$$

$$\sum_{\hat{t}\in C} X_{v,t,\overrightarrow{b}} = 1, \forall v \in F \tag{11}$$

$$\sum_{\hat{t}\in C} X_{v,t,\overleftarrow{b}} = 1, \forall v \in F \tag{12}$$

$$B_{v,\hat{t}} \geq B_{v,t} + t_{t,\hat{t}} - M(1 - X_{v,t,\hat{t}}), \forall t, \hat{t} \in C, v \in F \tag{13}$$

$$B_{v,j} = t.s, \forall v \in F, t \in C \tag{14}$$

The objective (8) is to minimize the number of FCSs used and total traveling distance. Constraints (9)–(10) collectively ensure that each task is served exactly once. Constraints (11)–(12) guarantee that the route of each FCS starts and ends at the base. Constraint (13) calculates the time at which FCS v begins the service task t, while (14) ensures the timely arrival at each surveillance location.

2) Constraint Programming:

$$\min \sum_{v\in F} M \cdot Z_v + \sum_{v\in F}\sum_{t\in N} \gamma_{typeOfPrev(SeqVeh_v, Tsk2V_{t,v}),t} \tag{15}$$

$$\text{s.t. } alternative(Tsk_t, [Tsk2V_{t,v}]_{v\in F, t\in N}) \tag{16}$$

$$noOverlap(SeqVeh_v, \gamma), \forall v \in F \tag{17}$$

$$first(SeqVeh_v, Tsk2V_{\overrightarrow{b},v}), \forall v \in F \tag{18}$$

$$last(SeqVeh_v, Tsk2V_{\overleftarrow{b},v}), \forall v \in F \tag{19}$$

$$Z_v \geq Z_{v+1}, \forall v \in 1, \cdots, f-1 \tag{20}$$

$$Z_v \geq presence(Tsk2V_{t,v}), \forall v \in F, t \in T \tag{21}$$

The objective (15) is to minimize the number of FCSs used and total traveling distance. Constraint (16) ensures that each charging task is served exactly once by one of FCSs. Constraint (17) ensures the travel time between surveillance locations. Constraints (18)–(19) guarantee that the route of each FCS starts and ends at the base. Constraint (20) breaks a symmetry and forces to use UAVs in order. Constraint (21) determines whether a UAV is used.

Figure 3 represents an optimal schedule of sample instance according to rendezvous design. FCS 1 departs from the base and arrives at location 2 at 62 to rendezvous with UAV 2. The same FCS visits UAV 1 at 157, UAV 2 at 252, UAV 1 at 357, UAV 2 at 442, UAV 1 at 557, UAV 2 at 632, and returns to the base, while FCS 2 serves UAVs 3 and 4. These two FCSs travel a total of 212 nautical miles to complete the mission.

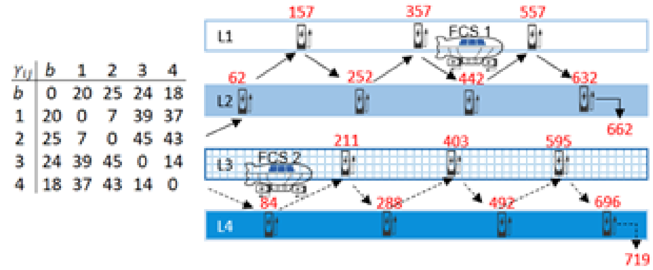

Fig. 3: Schedule of the sample instance according to rendezvous design.

C. Rendezvous Design with Limited Capacity of FCS

In the above rendezvous design, we assume an unlimited energy capacity of FCS, allowing each FCS to charge UAVs without limitation. However, FCS should recharge itself at the base station after charging multiple UAVs. Here we assume FCS must return to the base after charging a predetermined number of UAVs, q, before FCS resumes the mission.

The cumulated battery usage of FCS is represented by a function of time. For each FCS, we employ *cumulFunction* to capture energy consumption and recharging at the base. Let B represent the set of recharging tasks at the base.

$TskBase_{b,v}$ optional interval representing the j-th recharging task by FCS v at the base.
$SeqVeh_v$ collection of intervals $(Tsk2V \sqcup TskBase)$ assigned to FCS v
Y_v cumulative function to trace energy consumption and recharging for each FCS.

$$Y_v = step(0, q) - \sum_{t\in C} stepAtEnd(Tsk2V_{t,v}, 1) + \sum_{t\in B} stepAtEnd(TskBase_{t,v}, q), \forall v \in F \tag{22}$$

$$Y_v \leq q, \forall v \in F \tag{23}$$

Constraints (22)–(23) ensure FCS energy-level stays within limits. The constraints set the initial energy-level of FCSs at time 0, consume the energy as FCSs charge UAVs, and recharge FCSs at the base, throughout the planning horizon, by using a cumulative function with negative impact for energy consumption and a positive impact for recharging.

Figure 4 represents an optimal schedule of sample instance with limited capacity of FCS. In the illustration, FCS 1 departs from the base and provides charging services to UAVs 1 and 2. After completing 4 charges (q), FCS 1 flights back to the base and charges itself and resumes the mission. These two FCSs travel a total of 278 nautical miles to complete the mission.

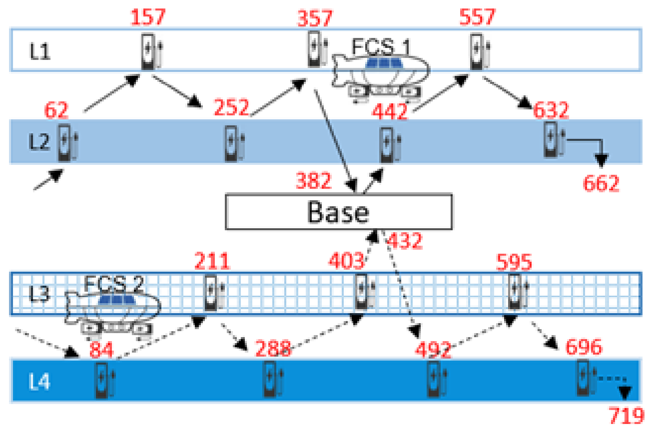

Fig. 4: Schedule of the sample instance according to rendezvous design with limited capacity of FCS.

IV. Computational Experiments

In this section, the effectiveness of the proposed model is examined. The MIP, CP, and flow control models are all coded in IBM OPL 20.1 on a personal computer with an Intel® Core i9-10885 CPU with 64 GB of RAM. The CPLEX codes (MIP and CP), benchmark instances and results are available at the following link: https://github.com/hamcruise/PersistentSurveillance

All our best efforts to borrow the benchmark instances from other authors were not successful. Therefore, we have arbitrarily generated benchmark instances and shared on Github. There are three classes of instances (A, B, C) with different UAV endurance durations $c(180, 240, 300)$ minutes, respectively. Each class consists of 12 instances. The number of surveillance locations vary 4 to 40. The class name and number of surveillance location determine the instance name. For example, A40 is the instance in class A with 40 locations. The duration of battery charging or swap (r) is set at 5 minutes. All locations are distributed across an 50 nautical mile square region with a single base at the center. The planning horizon is set to 1440 minutes.

Table I compares the hands-off vs. rendezvous. Column 1 identifies the name of the instance. Columns 2–4 give the results of the MIP for hands-off design, recording the minimum number of UAVs, according to different timelimits. When an instance could not find any feasible solution within the timelimit, the column has the '–' symbol. Columns 5–7 give the results of the MIP for Rendezvous design, recording the objective function values that capture minimum number of UAVs and total traveling distance. For instance, the instance A4 requires 3 UAVs to travel 469 miles, marked as 30469. Columns 8–10 give the results of the CP for rendezvous design and Column 11 report the optimality gap. When the corresponding MIP could not prove optimality, the column remains empty.

Figure 5 compares the two different designs in terms of the number of UAVs. The rendezvous design requires a smaller number of UAVs. For instance, the rendezvous requires 12

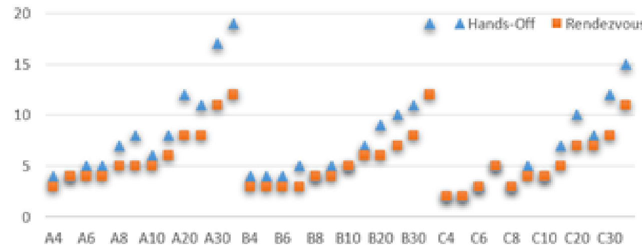

Fig. 5: Comparison of hands-off vs. rendezvous in terms of number of UAVs.

UAVs, compared to 19 by the hands-off in A30 instance. Table II reports a computational results of rendezvous design when FCSs have limited capacity. We assume FCSs must return to the base for self-charging after recharging 4 UAVs. The proposed MIP model failed to find any feasible solution within 600 s so the table reports only CP results. CP could not prove optimality of any of test instances and CP failed to find feasible solutions for large instances.

V. Conclusion

This paper offered a planning framework to recharging unmanned aerial vehicles assigned to persistent surveillance missions. The objective of this project was to allow the UAVs to remain on their missions without returning to the base for battery replenishment. We proposed a flying charging station in the form of blimps. The blimps mutually calculate a set of tours to locate, join and refuel all UAVs in the midst of ongoing missions. As a result, the UAV time in maintenance repose is lowered and mission extension options can be better managed. This project is illustrated with the use of a mixed integer programming model and a constraint programming to apprehend mathematical notion and negate unforeseen complexities.

A couple of areas can be foreseen for future research. The proposed MIP and CP models successfully proved optimality of many of test instances and found efficient solutions when the limited capacity of FCS was not considered. However, the proposed models failed to find efficient solution when the limited capacity of FCS was considered. Therefore, heuristic approaches are encouraged. Next, we will further study a similar problem when a surveillance mission requires a multiple heterogenous collaborative UAVs [21], [22]. For instance, certain mission task requires multiple UAVs equipped with specialized censors and radars.

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TABLE I: A comparison study of hands-off vs. rendezvous designs.

inst	Hands-Off (s)			Rendezvous (MIP)			Rendezvous (CP)			
	30	120	600	30 s	120 s	600 s	30	120	600	Gap
A4	4	4	4	30469	30469	30469	30469	30469	30469	0.00%
A5	4	4	4	40246	40246	40246	40246	40246	40246	0.00%
A6	5	5	5	40387	40387	40387	40387	40387	40387	0.00%
A7	5	5	5	40624	40624	40624	40630	40630	40630	0.01%
A8	7	7	7	50845	50845	50845	50916	50851	50850	0.01%
A9	8	8	8	50918	50918	50918	50959	50935	50935	0.03%
A10	6	6	6	51521	51521	51521	51556	51550	51550	0.06%
A15	8	8	8	61337	61337	61337	61596	61551	61498	0.26%
A20	12	12	12	–	81821	81821	82401	82247	82165	0.42%
A25	11	11	11	–	82286	82286	83291	82756	82601	0.38%
A30	17	17	17	–	–	–	114611	113348	113151	
A40	–	19	19	–	–	–	126086	124450	123988	
B4	4	4	4	30348	30348	30348	30348	30348	30348	0.00%
B5	4	4	4	30286	30286	30286	30286	30286	30286	0.00%
B6	4	4	4	30544	30544	30544	30544	30544	30544	0.00%
B7	5	5	5	30788	30788	30788	30788	30788	30788	0.00%
B8	4	4	4	40628	40628	40628	40631	40629	40629	0.00%
B9	5	5	5	40711	40711	40711	40711	40711	40711	0.00%
B10	5	5	5	50718	50718	50718	50778	50778	50778	0.12%
B15	7	7	7	61150	61150	61150	61296	61261	61241	0.15%
B20	9	9	9	61430	61430	61430	61565	61540	61533	0.17%
B25	10	10	10	–	71976	71976	72460	72374	72283	0.43%
B30	15	11	11	–	81784	81784	82320	82158	82089	0.37%
B40	–	19	19	–	–	–	124307	122973	122825	
C4	2	2	2	20233	20233	20233	20233	20233	20233	0.00%
C5	2	2	2	20484	20484	20484	20484	20484	20484	0.00%
C6	3	3	3	30514	30514	30514	30514	30514	30514	0.00%
C7	5	5	5	50436	50436	50436	50436	50436	50436	0.00%
C8	3	3	3	30574	30574	30574	30574	30574	30574	0.00%
C9	5	5	5	40744	40744	40744	40744	40744	40744	0.00%
C10	4	4	4	40634	40634	40634	40662	40661	40655	0.05%
C15	–	7	7	50928	50928	50928	50961	50960	50953	0.05%
C20	–	10	10	–	71086	71086	71303	71290	71290	0.29%
C25	–	8	8	–	71437	71437	71663	71579	71548	0.16%
C30	12	12	12	–	–	–	82012	81951	81923	
C40	36	15	15	–	–	–	113114	112470	112420	

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TABLE II: A computational results of rendezvous design with limited capacity of FCS

inst	Objective			Gap		
	30 s	120 s	600 s	30 s	120 s	600 s
A4	30816	30816	30816	2.65%	2.65%	2.65%
A5	40614	40610	40610	1.51%	1.50%	1.50%
A6	40653	40653	40649	1.61%	1.61%	1.60%
A7	41243	41188	41188	3.01%	2.88%	2.88%
A8	61609	61360	61356	2.61%	2.22%	2.21%
A9	71439	71254	71234	2.01%	1.76%	1.73%
A10	61819	61711	61665	2.94%	2.77%	2.70%
A15	–	–	–	–	–	–
A20	–	–	–	–	–	–
A25	–	–	–	–	–	–
A30	–	–	–	–	–	–
A40	–	–	–	–	–	–
B4	30504	30504	30504	1.65%	1.65%	1.65%
B5	30443	30443	30434	1.46%	1.46%	1.43%
B6	30869	30869	30869	2.82%	2.82%	2.82%
B7	30974	30974	30969	3.14%	3.14%	3.13%
B8	40850	40819	40819	2.08%	2.01%	2.01%
B9	41057	41056	41056	2.57%	2.57%	2.57%
B10	51090	51090	51090	2.13%	2.13%	2.13%
B15	71817	71817	71744	2.53%	2.53%	2.43%
B20	–	–	102325	–	–	2.27%
B25	–	–	–	–	–	–
B30	–	–	–	–	–	–
B40	–	–	–	–	–	–
C4	20306	20306	20306	1.51%	1.51%	1.51%
C5	20517	20517	20517	2.52%	2.52%	2.52%
C6	30590	30590	30579	1.93%	1.93%	1.89%
C7	50606	50606	50594	1.20%	1.20%	1.17%
C8	30704	30687	30687	2.29%	2.24%	2.24%
C9	40944	40944	40944	2.31%	2.31%	2.31%
C10	41013	40997	40997	2.47%	2.43%	2.43%
C15	51377	51332	51332	2.68%	2.59%	2.59%
C20	–	–	81843	–	–	2.25%
C25	–	112708	111967	–	2.40%	1.76%
C30	–	153005	152443	–	1.96%	1.60%
C40	–	–	–	–	–	–

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