Multiple UAV Coalition Formation Strategies

(Extended Abstract)

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ABSTRACT

A team of networked UAVs are deployed in an unknown region to search and destroy targets. To successfully destroy a target, a coalition of UAVs with sufficient cumulative resources needs to be assigned. Forming coalitions under networks with dynamic topology is difficult and the type of coalition formation strategy adopted affects the mission performance. In this paper, we determine a mechanism to form coalitions in dynamically changing networks and investigate different coalition formation strategies.

Categories and Subject Descriptors

I.2.9 [**Robotics**]: Autonomous vehicles; I.2.11 Distributed Artificial Intelligence [**Multiagent systems**]:

General Terms

Algorithms

Keywords

Networked robot systems

1. INTRODUCTION

Unmanned aerial vehicles (UAVs) have the ability to execute automated covert search and prosecute missions effectively. Usually, UAVs have limited sensor and communication range and can carry different types of resources that deplete with use. Sometimes, to completely destroy a target, different types and quantities of resources are required and hence the need for UAV coalitions. The UAV that detected the target is called the *coalition leader* (CL) whose task is to form a *coalition* that attacks the target simultaneously to induce maximum damage.

1.1 Coalition formation process

When an agent detects a target, the CL determines a set of resources that are required to prosecute the target and broadcasts a proposal containing this information to the rest of the team. Each agent receiving the proposal determines if it is devoid of any other assignments and has at least one type of resource required by the CL. If the agent satisfies these two conditions then it assumes a potential coalition members role (PCM) and broadcasts its bid to the CL with its available resources and the earliest time to arrive at the target (ETAT). The ETAT of an agent is the minimum time it takes to arrive at the target.

The CL receives the bids from PCM; determines a coalition using these bids; sends *accept* and *reject* decisions to the PCM. The PCM receive decisions and the accepted members modify their routes such that they prosecute the target simultaneously, while the rejected agents continue to perform their previous tasks. Once the coalition is formed, the CL and the PCM relinquishes their respective roles, while coalition members release their roles after prosecuting the target. The nature of the coalition formation strategy used can effect the performance of the mission.

1.2 Effects of limited communication range

To form a coalition, the proposal should reach all the agents. Due to limited communication ranges, the agents form a time varying dynamic network and the proposal propagates over this network causing delays in obtaining the information. As the network is dynamic, finding PCM is difficult because the agents may go out of communication range disrupting the communication network which is essential to form coalitions. Apart from this, the earliest time to arrive at target (ETAT) by an agent depends on the position of agent which changes by the time the CL makes a decision about coalition.

2. RELATED WORK

The coalition formation algorithms developed for multiagent systems [6, 5] cannot be directly applied to multirobots systems because physical resources cannot be transferred [8]. Vig and Adams [8] developed a coalition scheme where the tasks act as agents and perform the function of an auctioneer for gathering bids and determining the coalition using RACHNA. Parker and Feng [4] present a coalition formation scheme where a coalition leader robot broadcasts the existence of a task and other robots reply by providing their availability. In the above approaches, the robots do not face a situation where they can break the communication network during the coalition formation process since the robots can stop and form a static network until the coalition formation process is completed. However, this is not possible with multiple fixed-wing UAV groups due to constant motion. In this paper, we address two main issues (i) design several coalition formation strategies that can improve the mission performance and (ii) develop a mechanism to find

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potential coalition members from the time varying dynamic network formed by the UAV team.

3. PROBLEM FORMULATION

A search and prosecute mission is carried out on a bounded region $\mathcal{B}$, that contains M targets whose initial positions are unknown using N UAVs denoted as $A_i, i = 1, \ldots, N$. The UAVs can have different constant velocities and carry n different types of resources in limited quantities represented by a capability vector $\mathcal{R}_i^A =< R_{i1}^A, \ldots, R_{in}^A >$, where $R_{ip}^A,\ p = 1, \ldots, n$ represents the number of type-p resources held by agent A_i. Similarly, target T_j can have m- different types of resource requirements given as$\mathcal{R}_j^T =< R_{j1}^T, \ldots, R_{jm}^T >$, $j = 1, \ldots, M$, where $R_{jq}^T,\ q = 1, \ldots, m$ and $m \leq n$, represents the quantity of type-q resources required to prosecute the target T_j.

The UAVs have limited sensor range of r_s and communication range of at least $2r_c$ to avoid conflicts while forming coalitions. The UAVs are subjected to kinematic constraints preventing instantaneous course changes. The objective of the mission is to minimize the mission completion time. Let $\mathcal{T}$ represent the minimum mission time for a known environment (off-line solution). However, in our scenario, the environment is unknown, hence the agents carry out a search mission to detect targets and when a target is detected, a coalition is formed to destroy it. Therefore, mission completion time is a function of the employed search strategy (s) and coalition formation strategy S given as

$$\mathcal{T}(S) \leftarrow f(\mathcal{T}_s, \sum_{j=1}^{M} \mathcal{T}_j^S), \tag{1}$$

where, $\mathcal{T}(S)$ represents the mission time, $\mathcal{T}_s$ represents the search time to detect the targets, and $\mathcal{T}_j^S$ represents the time taken to prosecute target T_j using coalition formation strategy S. The objective (1) depends on s and S that are coupled. Hence, in this paper, we assume the agents use some fixed search strategy s, and we develop various coalition formation strategies (S) to achieve the objective of minimizing the mission time.

4. FINDING POTENTIAL MEMBERS

The UAVs need to form coalitions over a dynamic network. To determine a coalition, the CL requires the following information from the potential members: (a) earliest time to reach the target (ETAT) and (b) resources available for target prosecution. The ETAT cannot be determined using Dubins curves [2] because the agents are non-stationary and information delay occurs in the network.

To determine ETAT, the CL uses intermediate deadlines. The CL broadcasts the target and deadline for proposal submission, deadline to send decisions and deadline to prosecute the target. The CL will also broadcast the exact time at which coalition members are required to start the prosecution maneuver. A PCM uses this information to estimate its location when it (if part of coalition) is expected to start the prosecution maneuver, sending this information to the CL. We call this estimated location where a potential coalition member A_k expects to start its maneuver to prosecute target T_j as its *goal location* denoted by G_k^j. The G_k^j takes delay during information propagation into account. We assume a δ delay between nodes, otherwise the information is lost [3]. However, to determine PCM, we use the concept of time-to-live (TTL) from Internet Protocol [1]. TTL is a counter that determines the number of hops the packet can travel at most on its way from the source to the destination. Similarly, the CL broadcasts the proposal with a hop counter H_{max} which determines the maximum number of hops the proposal can travel. Using δ of the network and $H_{\max}$ counter, we can determine the maximum delay that can occur in the network and the PCM use this delay to determine their goal positions.

5. COALITION FORMATION STRATEGIES

We explore four different coalition formation strategies. They are (i) minimize the time to prosecute the target, (ii) minimize the coalition size, (iii) minimize time and the coalition size and (iv) minimize coalition size times the time to prosecute the target. Each of these strategies tries to achieve the goal of minimizing $\mathcal{T}_j^S$. Once the coalition is determined using any of the strategies, the CL sends accept and reject decisions with ETAT at the target to the accepted PCM. The accept members assume the role of coalition members and have to prosecute the target simultaneously (which is one of the mission requirements) [7].

We carried out extensive Monte-Carlo simulations to determine the performance of four strategies. From the results, on average, we found that the strategy (iii) is the best, as it minimizes the coalition size as well as the time to destroy the targets. Since, this strategy optimizes (i) and (ii), naturally it performs better. The strategy (iv) performs close to (iii) and is better than (i) and (ii). Further, investigation on the effect of search strategy s and the presence of moving targets on coalition formations will be reported later.

6. REFERENCES

[1] M. Clark. *Data Networks, IP and the Internet: Protocols, Design and Operation*. Wiley, New York, March 2003.

[2] L. Dubins. On curves of minimal length with a constraint on average curvature and prescribed initial and terminal positions and tangents. *American Journal of Mathematics*, 79:497–516, November 1957.

[3] L. Lamport. Using time instead of timeout for fault-tolerant distributed systems. *ACM Transactions on Programming Languages and Systems*, 6(2):254–280, April 1984.

[4] L. Parker and F. Tang. Building multi-robot coalitions through automated task solution synthesis. 94(7):1289–1305, 2006.

[5] T. Sandholm, K. Larson, M. Anderson, O. Shehory, and B. Tohme. Coalition structure generation with worst case guarantees. *Artificial Intelligence*, 111(12):209–238, 1999.

[6] O. Shehory. Methods for task allocation via agent coalition formation. *Artificial Intelligence*, 101(12):165–200, 1998.

[7] P. Sujit, J. George, and R. Beard. Multiple uav coalition formation. In *Proc. of the American Control Conference*, Seattle, Washington, June 2008.

[8] L. Vig and J. Adams. Market-based multi-robot coalition formation. In *Proc. of the International Symposium on Distributed Autonomous Robotic Systems*. Springer.