Multiple UAV Coalition Formation for a Search and Prosecute Mission

Joel George
Problem Description

Multiple UAVs with limited sensor ranges search for targets

A target found needs to be prosecuted

A UAV that detected the target may not have sufficient resources

Need to ‘talk’ to other UAVs to form a coalition for target prosecution

**Objective:** To find and prosecute all targets as quickly as possible

The algorithm should be scalable
Assumptions

Kinematic UAV model with constant velocity and radius of turn constraint

Limited sensor radius

Global communication

Limited resources that deplete with use

Stationary targets

Target locations are not know a priori

Rendezvous at target for prosecution
Three types of resources

Example

Target resource

The coalition \{UAV-1, UAV-2\} suffice to prosecute target
Coalition formation algorithm

UAV that detects the target – Coalition leader

Coalition leader requests for a coalition broadcasting target resources

Every UAV that has a required resource responds with information on available resources and cost (earliest time to arrive at target)

Coalition leader forms a suitable coalition

UAVs in coalition alter their path to rendezvous at target
**Coalition Formation Algorithm – Information Flow**

**Decision process for coalition leader $U_i$**

- **S1**
  - $U_i$ has all the resources
  - Determine path to target and prosecute it

- **S2**
  - $U_i$ has insufficient resources
  - Broadcast $T_j$ and $R_{T_j}^{U_i}$

- **Receive proposals for coalitions**
  - **Coalition feasible?**
    - Yes: Determine and broadcast $\tau_{cT_j}$ and $C(U_i,T_j)$
    - No: Broadcast 'discard coalition'

**Decision process for potential coalition member $U_k$**

- **Check if $U_k$ has any of the required resources for $T_j$**
  - Yes
    - Calculate $D_{U_k}^{T_j}$ and broadcast along with $R_{U_k}^{U_i}$
    - **In coalition?**
      - Yes: Determine path to target and prosecute it
      - No: No coalition interest

  - No
    - To other UAVs

- No coalition interest

From other UAVs

To other UAVs
Two stage algorithm for coalition formation

Stage I

Find a minimum time coalition

Stage II

Find a minimum member coalition

Example

Target resource requirement \((3,2,4)\)
Example

Potential coalition members, their resources and costs

<table>
<thead>
<tr>
<th>UAV</th>
<th>Resources</th>
<th>cost in seconds</th>
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<tbody>
<tr>
<td>U1</td>
<td>(2, 1,1)</td>
<td>123</td>
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<td>U2</td>
<td>(1, 3,0)</td>
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<tr>
<td>U5</td>
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Target resource requirement  (3,2,4)
Example: Stage I

Potential coalition members, their resources and costs

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Target resource requirement  (3,2,4)

Coalition members  \{U2, U3, U6, U1, U4\}

Coalition resources  (6,7,4)
## Example: Stage II

Potential coalition members, their resources and costs

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Target resource requirement \((3,2,4)\)

Coalition members \(\{U3, U1, U4\}\)

Coalition resources \((5,2,4)\)
Search and prosecute: 10 UAVs and 5 targets
Some rules

A UAV can be part of only one coalition

A UAV can be coalition leader for more than one targets

If same target is detected by multiple UAVs simultaneously, then the UAV with higher token number becomes coalition leader

If a UAV get simultaneous multiple coalition participation requests, then it responds to the coalition leader that is nearest
Optimal Coalition

Optimal solution to search and prosecute mission can be obtained via combinatorial optimization if targets locations are known a priori.

Particle Swarm Optimization for optimal solution

Need to consider sequence of prosecution and resource depletion.
Optimal prosecution: PSO solution
Time taken for a mission with 5 targets (with increase in number of UAVs)

Polynomial time algorithm fairs well when compared to the optimal solution obtained from PSO
Moving target

Constant velocity

Future location is known from position and velocity

If the UAV clocks are synchronized, then the extension from static to moving target is straightforward
Limited Communication Ranges

Results in a dynamic network

Every UAV acts as a relay node

Each hop has an associated lag

Time-to-live for a broadcast to avoid orphan messages

Message logging to avoid duplication
Coalition formation

Find a sub-network that is static over the coalition formation period

A UAV accepts to be a relay node only if it is in communication range for the entire coalition formation period

Works well as coalition formation period is much shorter than the time scale in which network connection varies
Coalition formation with limited communication ranges, communication delay, and moving target

Dotted circles around UAVs: sensor range
Lines between UAVs: communication links
Rendezvous at a maneuvering target is difficult → sequential prosecution

Coalition leader tracks the maneuvering target and broadcast this information until the target is in the sensor range of one of the coalition members

A coalition member prosecutes the target and continues to track it until the target is within the sensor range of the next coalition member
Coalition formation with limited communication range, communication delay, and maneuvering target: various cases

Coalition leader detects the target and has sufficient resources to destroy it.

Coalition leader does not have any resources. So coalition leader tracks the target until a coalition can detect the target. After this the coalition leader changes to search task.

The coalition leader first hits target and then continues to track the target until the next agent detects.
Limited communication range, communication delay, and maneuvering target
Summary

Coalition formation algorithm for search and prosecute mission

Moving and maneuvering target

Limited communication ranges and delays
Collaborators

P.B. Sujit
University of Porto

D. Ghose
Indian Institute of Science, Bangalore

R.W. Beard
Bingham Young University

J.B. Sousa, F.L. Pereira, and Jose Pinto
University of Porto
### Related Publications

<table>
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