Coalition Formation With Communication Ranges and Moving Targets

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Abstract—A team of unmanned aerial vehicles (UAVs) with limited communication ranges and limited resources are deployed in a region to search and destroy stationary and moving targets. When a UAV detects a target, depending on the target resource requirement, it is tasked to form a coalition over the dynamic network formed by the UAVs. In this paper, we develop a mechanism to find potential coalition members over the network using principles from internet protocol and introduce an algorithm using Particle Swarm Optimization to generate a coalition that destroys the target in minimum time. Monte-Carlo simulations are carried out to study how coalition are formed and the effects of coalition process delays.

I. INTRODUCTION

Unmanned aerial vehicles (UAVs) are widely used in search and prosecute missions. In a search-and-prosecute mission, multiple heterogeneous UAVs are deployed that perform the actions of detecting and prosecuting static and moving targets as a team. The UAVs have limited communication ranges and can have limited quantity of different types of resources which deplete with use. Due to limited communication ranges and UAVs motion, they form a time varying dynamic network. When a target is detected, the UAVs must cooperate with each other to prosecute the target simultaneously and in minimum time. Prosecuting the target simultaneously induces maximum damage to the target, while prosecuting the target in minimum time preserves fuel.

Depending on the nature of the detected target, there may be a necessity to assign a sub-team of UAVs to prosecute it. We refer to this sub-team of UAVs as a coalition, UAVs in the coalition as coalition members (CM), and a UAV that detected the target as the coalition leader (CL).

A. Coalition formation process

When an agent detects a target, it determines a set of resources that are required to prosecute the target completely. If the agent does not have sufficient resources at its disposal, then it assumes a coalition leader (CL) role whose task is to form a coalition such that the cumulative resources of the coalition suffice the target requirement. For this task, the CL broadcasts a proposal to the rest of the team containing information of the target and its required resources.

Each agent receiving the proposal determines, if its devoid of any other assignments and has at least one type of resource required by the coalition leader. If the agent satisfies the 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 location (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 the decisions and send their acknowledgements to the CL. The members accepted for the coalition 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 CM release their roles after prosecuting the target.

B. Effects of limited communication range and moving targets

To form a coalition, the coalition request proposal from the CL should reach the rest of the agents. Due to limited communication ranges, the agents form a time varying dynamic network. So the coalition request has to propagate over the network. Because of message propagation, the receiving nodes obtain the information with some delay.

Since the network is dynamic, finding potential coalition members is difficult, because the network relay nodes (other agents) may go out of communication range and may not be able to communicate, thus 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 coalition leader makes a decision about coalition. Also, the ETAT varies with time for the moving target.

In this paper, we develop solutions that addresses the above issues. First we determine potential coalition members from a time varying dynamic by using concepts from internet protocol. Then, we develop a technique to estimate ETAT that is constant through out the coalition formation process thus providing a good metric for the coalition formation algorithms. This ETAT is used to implement a new coalition formation algorithm based on Particle Swarm Optimization (PSO).

II. RELATED WORK

A coalition is a group of team members that have agreed to cooperate and coordinate with each other in executing a single task. Determining the optimal coalition from a group of agents is a computationally intensive task and is NP-hard [3]. Vig and Adams [4] 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 [5] present a coalition formation scheme where a coalition leader robot broadcasts the existence of a task and other robots reply by providing their availability. The leader robot evaluates all possible coalitions and sends an accept decision to the robots that it considers suitable. 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 in multiple fixed-wing UAV groups due to constant motion. Vanzin and Barber [7] determine a mechanism of finding potential members for coalition based on TCP protocol. However, the technique does not address the coalition formation issues. Therefore, we develop new techniques to determine coalition in a dynamic network.

III. PROBLEM FORMULATION

A. The mission

A search and prosecute mission is carried out on a bounded region \( B \) using \( N \) UAVs (also called as agents), that contains \( M \) targets whose initial positions are unknown (as shown in Figure 1). The UAVs have different velocities and carry different types and quantities of resources. Each UAV has a unique token number \( A_i, i = 1, \ldots, N \). We assume that the UAVs have the capacity to carry \( n \) types of resources represented by a capability vector \( R^A_i < R^A_{i1}, \ldots, R^A_{in} > \), \( i = 1, \ldots, N \) where \( R^A_{ip}, p = 1, \ldots, n \) represents the number of type-\( p \) resources held by agent \( A_i \).

The UAVs carry out a search task to locate targets through their sensors that have a limited sensor range of \( r_s \). When \( A_i \) detects a target \( T_j \) as shown in Figure 1, we assume that it can ascertain the type of resource required to prosecute the target. If \( m \)–different types of resources and quantities are required to engage target \( T_j \), then the resource requirement vector is represented as \( R^T_j = < R^T_{j1}, \ldots, R^T_{jm} > \), \( j = 1, \ldots, M \) where \( R^T_{jq}, q = 1, \ldots, m \) and \( m \leq n \), represents the quantity of type-\( q \) resources required to prosecute the target \( T_j \).

Each agent has a communication range \( (r_c) \) and assume that the communication range of an agent \( A_i \) is at least twice that of the sensor range (that is, \( r_c > 2r_s \)). If the communication range is less than \( 2r_s \) then multiple agents that are not within the communication range of each other can detect the same target resulting in multiple coalitions for the same target.

When a target \( T_j \) is located by \( A_i \), it determines if it has sufficient resources. If it has then it will prosecute the target. Otherwise, it assumes the coalition leader role (CL) for the target and has to form a coalition over the network as shown in Figure 1. The issue of determining the potential coalition members (PCM) for a coalition through the dynamic network is addressed in Section IV.

Recall from Section I-A, that when CL receives bids from PCM, it is tasked to determine a coalition. The selected coalition should satisfying other requirements, that include, (i) minimizing the time-to-prosecute the target and (ii) minimizing the number of UAVs in the coalition. The coalition formed by agent \( A_i \) for target \( T_j \) is represented as \( C^A_i \) and the cumulative coalition resources as \( R^C_{ij} \). The objective (i) is desirable as it minimizes the fuel usage during a specific prosecution and the objective (ii) ensures that the UAVs distribute their search effort so that the targets are detected quickly and the mission of finding and prosecuting all the targets is accomplished quickly. The objective also aims to preserve fuel.

Let \( \Lambda \) be the set of all potential coalition members including the coalition leader bidding to be part of the coalition formed by agent \( A_i \) and \( \lambda_k \) be the ETAT of the agent \( A_k \in \Lambda \). The objective function that the coalition leader has to solve to determine a coalition is given as:


\[
\text{Objective : } \min_{\Lambda} \max_{k:A_k \in \Lambda} \lambda_k \tag{1}
\]

Subject to : \( \sum_{k:A_k \in \Lambda} R^A_{kp} \geq R^T_{jp}, \text{ for all } p = 1, \ldots, n \tag{2} \)

where \( \Lambda \subseteq \Lambda \). The objective function determines a coalition \( \Lambda \) that has a minimum latest arrival time. We use the latest time of arrival at the target (LTAT) and not ETAT because, the LTAT of \( \Lambda \) determines the ETAT of the coalition to prosecute the target simultaneously and the objective function chooses a coalition which will minimize this.

The solution to the optimization problem (Equations 1 and 2) can be computationally intensive as the number of agents increase. Therefore, we use the coalition formation algorithms developed in [1] that has low computational complexity when the targets are stationary. However, the same coalition formation algorithms cannot be used for moving targets cases. Hence, we developed a new coalition formation algorithm using Particle Swarm Optimization (PSO) which is described in Section V.

B. UAV Kinematics

The UAVs are subjected to kinematic constraints preventing instantaneous course changes. We assume that each UAV is located at different unique altitudes and hence there is no need for collision avoidance. We also assume that each UAV has a different velocity \( v_i \) and the autopilots of the UAVs hold the altitude and maintain the ground speed.
The kinematics of the UAVs are modeled using first order kinematics as
\[
\begin{align*}
\dot{x}_i &= v_i \cos \psi_i \\
\dot{y}_i &= v_i \sin \psi_i \\
\dot{\psi}_i &= k(\psi_d - \psi_i)
\end{align*}
\]
(3)
where \(\psi_d\) is the desired heading of the UAV, \(\psi_i\) is the current heading, \(v_i\) is the ground speed, and \(k\) is the autopilot gain. We assume heading rate is constrained to
\[
-\omega_{\text{max}} \leq \dot{\psi} \leq \omega_{\text{max}}
\]
(4)

C. Target kinematics

We assume that moving targets have a constant heading until they reach the boundary \(B\). Although the assumption of non-maneuvering targets is not realistic, it allows us to address the ability of the coalition formation algorithm to handle situations with moving targets as well as to verify the mechanism of determining potential coalition members in a dynamic network. Moreover, this situation is true for targets moving on straight roads [9]. The kinematic model of the target is:
\[
\begin{align*}
\dot{x}_j^T &= v_j^T \cos \psi_j^T \\
\dot{y}_j^T &= v_j^T \sin \psi_j^T \\
\dot{\psi}_j^T &= 0.
\end{align*}
\]
(5)
where, \(v_j^T\) is the velocity of the target \(T_j\), \(\psi_j^T\) is its heading. We assume that the velocities of all the targets are less than the velocities of any of the UAVs. When a target reaches the boundary of \(B\), we assume that the target makes an random maneuver to enter back into the boundary. This condition forces the CL to form a coalition that prosecute the target before it reaches the boundary or discard the coalition if that is not feasible.

IV. NETWORK MODEL TO DETERMINE POTENTIAL COALITION MEMBERS

The UAVs need to form coalitions over a dynamic network. To determine a coalition, the coalition leader 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 is determined using Dubins curves [2] that requires the target and the UAV to be stationary during computation. However, in the present case, both are non-stationary, hence the ETAT from the current location cannot be used. The agents have to determine ETAT that holds for the entire coalition process (Section I-A).

In order to determine invariant ETAT, the coalition leader uses intermediate deadlines to receive the information and to form coalitions. The coalition leader will broadcast the availability of the target with the deadline for proposal submission, the deadline to send decisions and the deadline to execute the target. The coalition leader will also broadcast the exact time at which the coalition members are required to start the execution maneuver. A PCM uses this information with its current state to estimate its location at the time when it (if part of coalition) is expected to start the execution maneuver and send this information to the coalition leader. We call this estimated location at which a PCM \(A_k\) expects to start its execution maneuver as its goal location denoted by \(G_k\).

The CL uses the goal location and the resources information from the received bids to determine a coalition. Decisions are sent to PCM according to the prescribed send decisions deadline. The accepted agents reach their determined location (\(G_k\)) and execute their simultaneous arrival maneuver using modified Dubins curves [1] to arrive simultaneously at target \(T_j\). On the other hand, the rejected agents continue their previous task.

Determining potential PCM in a dynamic environment is difficult. In Figure 1 agent \(A_1\) broadcasts the target information to its immediate neighbors. Say, at time \(t\), the agent \(A_1\) broadcasts to its neighbors. The broadcast will be delivered if no faults occur to the neighbors at time \(t + \delta\), where \(\delta\) is the time taken by the message to reach the neighboring agent. The value of \(\delta\) can be considered a constant taking the value of the largest possible delay in the network [6].

However, to determine PCM, the broadcast has to travel in the network, but the question is how long? If there is no time limit, then the broadcast may live in the network forever. Hence, we use the concept of time-to-live (TTL) from Internet Protocol [8]. 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. When the packet reaches a node, the value of the TTL is reduced by one and sent to its neighboring nodes. This process is carried on until packet reaches the destination or the TTL counter reaches 0 where it is dropped. Similarly, the coalition leader broadcasts the proposal with a hop counter \(H_{\text{max}}\) determines the maximum number of hops the proposal can travel.

We know that there exists a \(\delta\) which is constant for communication to happen between nodes and also there exists a \(H_{\text{max}}\) that determines the depth of the network. So, the coalition leader can use \(\delta \times H_{\text{max}}\) as a measure to determine the proposal submission time, time to send decisions, and the time to execute the target. The proposal submission time will be \(2\delta H_{\text{max}} + \Delta_w\), where \(\Delta_w\) is the time window allowed to the agent to receive other proposals so that it can use the cumulative information available in that time window to decide whom to send. Once the information is received by the coalition leader, it takes \(\Delta_c\) time units to determine the coalition. Then the coalition leader will broadcast the decision which will take \(\delta H_{\text{max}}\) time units to reach the last agent in the network. Therefore, the time to start the target prosecution maneuver by the coalition formed by \(A_1\) to target \(T_j\) is \(\zeta_j^i - 3\delta H_{\text{max}} + \Delta_w + \Delta_c\) time units.

The agents in the network use \(\zeta_j^i\) to determine their goal positions (\(G_k^i\)) for bidding as well as to take a decision on whether to be a relaying agent or not.

Coalition leader \(A_i\) predicts the \(\zeta_j^i\) for target \(T_j\) and
broadcasts the request in the form:

$$P^j_i = \langle A_i, Z^j_i, R^j_i, H^j_i, H_{max}, \zeta^j_i, \tau^j_i \rangle \ (6)$$

where $Z^j_i = [x^j_i, y^j_i]$, represents the location of the target $T_j$, $H^j_i$ is the current hop counter which is initially set to $H_{max}$ and $\zeta^j_i$ is the time to start the prosecution maneuver. The entry $\tau^j_i \in \{0, 1\}$ represents the target status flag. When $\tau^j_i = 1$, $T_j$ is a moving target otherwise it is a stationary target.

Each agent, say $A_k$, in the network can be a relaying agent or a coalition member (can also be a coalition leader) or both. To consider the relaying role offered by $A_i$, $A_k$ has to be in the communication range for the complete $\zeta^j_i$. Assume that $A_k$ is located at $Z_k = [x_k, y_k]$ with heading angle $\psi_k$, then it estimates its goal position $G^j_k$ as

$$G^j_k = [x_k + \zeta^j_i v_k \cos \psi_k, y_k + \zeta^j_i v_k \sin \psi_k]. \ (7)$$

For $A_k$ to be a relaying agent for $A_i$, both the agents should be within the communication until they reach their respective goal positions, that is, they need to satisfy the following condition

$$|G^j_i - G^j_k| \leq r_c. \ (8)$$

The neighboring agents $A_k \in N_i$ (where $N_i$ contains all the agents within the communication range of $A_i$) form the primary nodes for the network centred at $A_i$. The node becomes a relaying node if it satisfies the communication constraint condition given in Equation 8. The same node can also be a PCM if it satisfies the resource requirement condition given in Equation 9.

$$R^A_{kp} > 0 \text{ and } R^P_{jip} > 0, \text{ for some } p \ (9)$$

That is, if the agent has at least one type of resource required by the target then it becomes a PCM. The role of agent $A_k$ changes from PCM to CM, if it receives an acceptance from the CL. As a relaying agent, the agent $A_k$ decreases the hop counter $H^j_k$ and checks if $H^j_k$ is positive, if so, then it broadcasts the proposal to its neighbors otherwise it will drop.

During the coalition formation process, there can be cycles like $A_i$ broadcasting to $A_k$ and $A_k$ broadcasting it back to $A_i$. The agents screen the messages to prevent it from being re-broadcast. To screen the message, the node $(A_k)$ receiving the message logs the message as:

$$L^j_k = \langle A_i, T_j, \zeta^j_i, e^k_i \rangle \ (10)$$

where, $e^k_i \leftarrow t + \zeta^j_i$ is the log message expiry time and $t$ is the current time. For a tighter bound on the log expiry time $e^k_i \leftarrow t + \zeta^j_i - \delta(H_{max} - H^j_k)$. Initially, $A_k$ checks if there is an entry in $L^j_k$ with the same agent $A_i$, target $T_j$ and $\zeta^j_i$. If an entry exists then $A_k$ will not broadcast, otherwise a broadcast will happen. When $t > e^k_i$, the log message is erased from $L^j_k$. The CL determines a coalition by $\zeta^j_i$, hence considering $\zeta^j_i$ as an upper bound for message expiration is a valid assumption.

During the coalition formation process, an agent can receive multiple requests from various CLs for PCM and relaying agent roles for their respective coalitions. In order to have conflict free decision-making we design the following rules.

Rule 1 If $A_i$ is a coalition leader for target $T_j$ and it detects another target $T_s$. Then $A_i$ can also be a coalition leader for $T_s$.

Rule 2 At any time $t$, an agent can bid to be a potential coalition member for only one coalition. The agent can take coalition leader and relaying agent roles for multiple targets but not the role of a coalition member.

Rule 3 If agent $A_i$ receives multiple requests to be part of different coalitions and $A_i$ is uncommitted then it will select a coalition leader that is nearest.

Rule 1 is designed to reduce further information exchange between the agents to share the role of coalition leader for $T_s$ as the process can contribute to additional delays resulting in no coalitions. The Rule 2 is required to ensure that one agent is not part of multiple coalitions. However, it can be part of multiple simultaneous coalitions as a relay member or as a coalition leader. At the same time, if the agent $A_i$ receives multiple requests then it will select a coalition leader which is nearest. Other possible selection schemes for the agents could be time stamp of the arrived request, ETAT, token number, etc. Once the coalition leader receives the responses from its neighbors then it will determine the coalition.

V. COALITION FORMATION

The coalition leader needs to determine a coalition such that the obtained coalition prosecutes the target in minimum time and has the smallest coalition. For this, the CL requires ETAT and their resources from the PCM. As described in Section III-A, the coalition formation algorithm developed in [1] can be used for stationary targets but not for moving targets.

The CL broadcasts the proposal $P^j_i$ through the network. When PCM receive the coalition broadcast, they respond using the following format:

If $\tau^j_i = 1$:

$$Q^j_k = \langle A_k, A_i, T_j, R^T_k, \psi_k, G^j_k, v_k \rangle \ (11)$$

else

$$Q^j_k = \langle A_k, A_i, T_j, R^T_k, C_k \rangle \ (12)$$

where $C_k$ is the Dubins distance from the goal position to the target location, the calculation of which can be found in [1]. In the case of moving target, the potential coalition member sends its estimated goal position using (Equation 7), heading and velocity. Let $Q_i$ be the set of proposals received by the CL $A_i$. The CL has to determine the smallest coalition that can prosecute the target in minimum time using $Q_i$. Since, the problem is a multi-objective (Equation 1), we use a particle swarm optimization technique (PSO) to provide a solution.
Unlike in the static target case where the PCM broadcast ETAT and the CL determines the coalition, in the moving targets case, the PCM send their goal positions with heading angles and the CL determines the ETAT and the target prosecution location. For a moving target case, the CL does not know the possible PCMs and their goal locations to determine ETAT while broadcasting $P^J_i$. Although, the coalition formation process for moving targets appear to be more centralized than for static targets, the system in general is decentralized as any agent can become a coalition leader and form a coalition and also the network is not constrained to be of a fixed topology.

A. Solution using PSO

Particle swarm optimization (PSO) is a population based stochastic optimization technique developed by Eberhart and Kennedy [10]. The dimension $(D)$ of the particle $x_i$ depends on the number of bids received by the CL, therefore $D = |Q_i|$. Consider a swarm of particles $S$ where each particle $x_i, l = 1, \ldots, S$ and each particle is represented as $x_i = (x_{i1}, \ldots, x_{id})$ and $x_{id} \in \{0, 1\}, d = 1, \ldots, D$. Each dimension of a particle corresponds to a PCM. A value of 1 for a dimension indicates that the PCM corresponding to that dimension is part of the coalition determined by that particle. For each particle, the ETAT and the number of agents in the coalition are determined. The PSO optimizes these two parameters to provide us the best solution. Since the time to compute the solution is fixed to $\Delta_c$ time units, the number of PSO iterations are restricted to $\Delta_c$. This gives us the best possible solution for a given $\Delta_c$. The procedure to determine the coalition is given in Algorithm 1.

Algorithm 1 Coalition formation using PSO algorithm

1: Initialize: $S, \Delta_c, D, t, \text{stime} = \text{cputime} + \Delta_c$, stime0 = \text{stime}, \text{btime} = \infty, P = 1_{1 \times |Q_i|}, \text{bPos}.
2: while \text{stime} $\geq$ 0 do
3: for $l = 1 : S$ do
4: \hspace{1em} [time, tpos] $\leftarrow$ \text{determineCoalition}($X_l, Q_i, R^J_i$)
5: \hspace{1em} if time $< \text{btime}$ and $\sum X_l \leq \sum P$ then
6: \hspace{2em} \text{btime} = time \% best ETAT
7: \hspace{2em} $P = X_i$ \% smallest coalition
8: \hspace{1em} \text{bPos} = tPos \% Best target prosecution location
9: end if
10: end for
11: update position and velocities of the swarm using Equations ?? and ??.
12: \text{stime} = \text{stime0} $-$ \text{cputime}
13: end while

The CL executes Algorithm 1 until stime reaches zero. During each iteration, for each particle $X_l \in S$, the function determineCoalition is evaluated. The function returns the moving target intercept time and the location of intercept (line 4). The time to intercept the target for a coalition corresponding to a particle in the current iteration is compared with the previous best time to intercept the target (line 5) along with coalition size. If the coalition corresponding to the current particle is able to meet the objectives with lower time than the previous best time and with smaller or same coalition size then the best prosecution time and the best particle is updated (lines 6 and 7). The velocities and positions of the particle is updated (line 10). Then the new stime is determined, if stime is positive then another iteration is carried out otherwise, the best particle $P$ and the time are returned as the smallest coalition and the ETAT (line 11).

The determineCoalition function determines the coalition for a particle $X_l$. The entry $x_{id}, d = 1, \ldots, D \in X_l$ represents an agent in the coalition. If $x_{id} = 1$ then it is in the coalition otherwise $x_{id} = 0$ (line 4 of Algorithm 2). If an agent is determined to be part of the coalition, then its resources are added to $R_s$ which is the cumulative resource vector for entire coalition (line 5). Then the goal positions, velocities, and heading angles of all the agents in the coalition are grouped together (line 6) to be passed on to the function bisecMethod (line 10) if the combined resources of the coalition are sufficient to prosecute the target (line 9).

B. Bisection method

Given a coalition, the bisection method determines the minimum time and the prosecution location of the target iteratively. Assume that the coalition begins the target execution maneuver at time $t_e$, then this coalition must prosecute the target before it reaches $B$. Assume the target takes time $t_b$ to reach at a point $\pi$ on the boundary $B$. Therefore, the trajectory interval for prosecuting the target is represented as $I = [\psi^i_j, \pi]$. Check if the coalition can prosecute the target at the point $\pi$. If the coalition is unable to prosecute the target by $t_b$ then the coalition is dissolved. Otherwise, interval $I$ is a valid trajectory. Choose a midpoint in the interval $I$, say $\pi'$. Determine if the coalition can prosecute at $\pi'$, if so then
consider the new interval as $I = [G^i, \pi']$, otherwise the new interval will be $I = [\pi', \pi]$. This iterative process is continued until a desired accuracy is reached. We are currently using bisection method due to its simplicity.

VI. Simulation Results

Through Monte-Carlo simulations, we study the effect of hop count $H_{\text{max}}$ and communication process delays $\delta$. The coalitions for the targets are formed using the developed potential coalition member finding technique and PSO based coalition formation algorithm.

We conducted an experiment with 10 UAVs and 5 targets (3 moving and 2 stationary) in a region of 1000m x 1000m. The position of the vehicles and targets and heading angles of the moving targets and the UAVs are randomly generated. The velocities of the UAVs are randomly generated between 15 and 30m/s, while the velocities of the moving targets are randomly generated between 5 and 15m/s. The vehicle ranges are $r_v = 150m$ and $r_c = 375m$, the PSO parameters are $\omega = 0.7 - 0.4$, $c_1 = 2$, $c_2 = 2$, $\chi = 0.25$, $\sigma = 20$, $D = 4$, $H_{\text{max}} = 2$, $\delta = 0.1s$, $\Delta_e = 0.3s$, and $\Delta_w = 2\delta$. Each simulation was carried out for 500 seconds and we record the time each simulation takes to prosecute all the 5 targets. If all the targets are not prosecuted then the time is considered to be 500 seconds for that simulation. The communication process time $\delta$ is varied from 0.1s to 0.3s in steps of 0.2 seconds, while the maximum number of hops $H_{\text{max}}$ is varied from 1 to 3.

Figure 2 shows the average mission time taken by the UAVs to prosecute all the targets for a given $\delta$ and maximum number of hops $H_{\text{max}}$. First, we will study the effect of increase in $H_{\text{max}}$ for a given $\delta$. Consider the performance curve with $\delta = 0.1s$ and varying $H_{\text{max}}$ from 1 to 3 as shown in the Figure 2. For $\delta = 0.1$, with increase in $H_{\text{max}}$ from 1 to 2, the performance increases, that is, the mission time decreases. This is because, the coalition leader can get more potential coalition members from the UAV network and hence has better choices to make a coalition that will prosecute the target quicker. However, further increasing $H_{\text{max}} = 3$, the performance is slight lower than $H_{\text{max}} = 2$, as the delays involved due to increase in $H_{\text{max}}$ play a role in reducing the performance marginally.

When $\delta = 0.3s$, we can see from the figure that the performance increase with increase in $H_{\text{max}}$ as the coalition is able to get better potential coalition members. However, the performance of $\delta = 0.3s$ is lower than $\delta = 0.1s$. This happens only due to accumulation of delays. The performance degrades significantly due to higher delays and hence the coalition leader was unable to form coalitions when the delay is further increased to $\delta = 0.5s$.

The second effect that can be studied from the Figure 2 is the effect of increase in $\delta$ for a given $H_{\text{max}}$. From the figure, we can see a natural phenomena, where with increase in $\delta$ the performance degrades correspondingly. We carried out 100 different experiments to study the effects of delays and maximum hop counter. All the experiments showed similar performance curves as shown in Figure 2. From these studies, it shows that selection of $H_{\text{max}}$ and the delays involved during communication plays a role in the performance of the mission.

VII. Conclusion

In this paper, we presented a framework based on concepts from Internet Protocol to determine potential coalition members in a time varying dynamic network formed by UAVs having limited communication ranges. We developed a new coalition formation algorithm using particle swarm optimization and bisection method that determines time invariant ETAT for moving targets during the complete coalition formation process time and provides the best possible solution for a given coalition computation time. The results show that for a given coalition formation time, an increase in $H_{\text{max}}$ can increase the performance but larger values of $H_{\text{max}}$ can affect the performance.

References