A Flocking Algorithm with Restrictive Partnership Models for Ad Hoc Networks

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***Abstract*— This paper presents a flocking algorithm to increase the connectivity of a mobile ad hoc network using autonomous and intelligent agents. Flocking algorithms usually aim to simulate realistic movements of a group of agents. In this paper, however, agents use a flocking algorithm to find a solution to a computationally very difficult optimization problem in real-time as the topology of the network changes due to the mobility of users. In the new flocking algorithm, agents select their interaction partners based on the Gabriel or Delaunay triangulations. A simulation study is conducted to compare the performance of alternative methods of selecting interaction partners.**

I. Introduction

An ad hoc network is a communication network that is established spontaneously by a set of devices that can communicate without requiring a fixed communication infrastructure. As wireless communication technologies are increasingly integrated into a variety of devices, mobile ad hoc networks (MANETs) have found a wide range of viable real-life applications such as military missions, emergency response, and search/rescue operations. The topology of a MANET is dynamic because its nodes move freely. Therefore, maintaining an acceptable level of Quality of Service (QoS) in MANETs is a challenging task.

In the literature, several papers propose the use of special mobile nodes to augment the topology of a MANET dynamically as the nodes move [1-6]. These special nodes, called *agents*, monitor the state of the network and dynamically adjust their locations to support the connectivity of other nodes (or user nodes). These agents are only aware of the nodes that they can directly communicate with [3, 4]. Agents make their deployment decisions independently based on interactions with their local neighbors. They use simple rules to determine their new locations as the topology of the network changes. In the context of mobile robots, the function of flocking algorithms is to keep the robots together and avoid obstacles while performing a task. However, the problem under consideration in this paper is quite different because user nodes are assumed to move randomly. This short paper claims that in a flocking algorithm, the interaction partners of an agent should be determined from a limited set of its neighbors. The paper proposes to use the Gabriel and Delaunay Triangulation to determine the interaction partners of an agent and compares the performance of these approaches against a complete set of neighborhoods.

II. Problem Description

Consider a MANET $G(t)$ with a node set $N(t)$ and edge set $E(t)$ at time t (i.e., $G(t)=(N(t),E(t))$. There are two types of nodes, user nodes (set $U(t)$) and agent nodes (set $A(t)$). User nodes move randomly. The nodes communicate over wireless links that are established if two nodes are within one another's communication range. Let point $\mathbf{p}_i(t)=(x_i(t),y_i(t))$, $x_i(t)\in\mathbb{R}$ and $y_i(t)\in\mathbb{R}$, represent the location of node i at time t. Then, edge set $E(t)$ of the network at time t is defined as $E(t)=\{(i,j): i,j\in N(t), i\neq j, d_{ij}(t)\le \min(R_i,R_j)\}$ where R_i is the communication range of node i, and $d_{ij}(t)$ is the Euclidean distance between nodes i and j (i.e., $d_{ij}(t)=\|\mathbf{p}_i(t)-\mathbf{p}_j(t)\|$ where $\|\mathbf{p}\|$ denotes the Euclidean norm of vector $\mathbf{p}$).

The mission time of the network is divided into T discrete time intervals. The objective of agent nodes is to maximize the connectivity of user nodes as the network topology changes during the mission time. The problem is defined as follows:

$$\text{Max} \quad Q=\frac{200}{T(|U(t)|(|U(t)|-1)}\sum_{t=1}^{T}\sum_{i\in U(t)}\sum_{j\in U(t):i<j}\tau_{ijt}$$

subject to:

$$\|\mathbf{p}_i(t)-\mathbf{p}_i(t-1)\|\le V_i \quad \forall i\in A(t), t=1,\dots,T$$

where τ_{ijt}=1 if there is a path between user nodes i and j at time t, and τ_{ijt}=0 otherwise. The constraint of the problem states that each agent i can move a maximum of V_i unit distance between two consecutive time periods.

III. Proposed Flocking Algorithm

In the flocking algorithm defined by Konak et al. [4], the movement of an agent node is defined as

$$\mathbf{p}_i(t+1)=\mathbf{p}_i(t)+\frac{\min(V_i,\|\mathbf{v}_i(t)\|)}{\|\mathbf{v}_i(t)\|}\mathbf{v}_i(t) \qquad (1)$$

where $\mathbf{v}_i(t)=(vx_i(t),vy_i(t))$ is the velocity vector of agent i, indicating the direction and the distance that agent i intends to travel from period t to t+1. The velocity vector $\mathbf{v}_i(t)$ is calculated based on the agent's interactions with its neighbors at time t as follows:

$$\mathbf{v}_i(t)=\begin{cases}\alpha\sum_{j\in N_i(t)}\mathbf{v}_{ij}(t)+(1-\alpha)\mathbf{v}_i(t-1) & N_i(t)\neq\{\} \\ \alpha V_i(\cos(\theta),\sin(\theta))+(1-\alpha)\mathbf{v}_i(t-1) & N_i(t)=\{\}\end{cases} \qquad (2)$$

where $N_i(t)$ is the set of the topological neighbors of agent i, α is a memory parameter (between 0 and 1), and $v_{ij}(t)$ is the velocity of agent i with respect to its interaction partner node j as follows:

$$\mathbf{v}_{ij}(t)=\begin{cases}0.5\dfrac{(d_{ij}(t)-SA)}{d_{ij}(t)}(\mathbf{p}_j(t)-\mathbf{p}_i(t)) & j\in A_i(t)\\ \dfrac{(d_{ij}(t)-SU)}{d_{ij}(t)}(\mathbf{p}_j(t)-\mathbf{p}_i(t)) & j\in U_i(t)\end{cases} \quad (3)$$

where set $U_i(t)$ and $A_i(t)$ represent the sets of user and agent interaction partners of agent i at time t ($N_i(t)=U_i(t) \cup A_i(t)$) and SU and SA are the target distances that agent i seeks to maintain between its user and agent interaction partners, respectively.

In [4], the set of interaction partners of agent i includes all nodes that the agent has a link with. Therefore, an agent may be heavily influenced by its interaction partners that are clustered together. In this paper, we define two new interaction partnership modes based on the Gabriel and Delaunay triangulations. In these new partnership modes, agent i interacts with its neighbor node j according to the following rules:

- *Delaunay Triangulation Mode*: If there is no other node inside the circumcircle of the triangle formed by $\mathbf{p}_i(t)$, $\mathbf{p}_j(t)$, and $\mathbf{p}_k(t)$ for all $k\in N_i(t)$.
- *Gabriel Triangulation Mode:* If there is no other node within the circle where the line segment connecting $\mathbf{p}_i(t)$ and $\mathbf{p}_j(t)$ is a diameter.

IV. Computational Experiments & Conclusion

The simulation environment defined in [4] is used to test the performance of the new partnership modes. The user nodes are randomly moved within a circle of the radius of 300-unit distance. In each time step t, user node $i\in U(t)$ changes its direction angle $\theta_i(t)$ randomly between 0 and 2π with a probability of ρ. Then, the user node travels a random distance between $V_{\min}$ and $V_{\max}$ in the direction of angle $\theta_i(t)$.

In simulation experiments, the three versions of the partnership modes were compared using various test networks with 20, 30, 40, and 50 user nodes and 2, 4, 6, 8, and 10 agents. The parameters of the user mobility simulation were $V_{\min}$=5, $V_{\max}$=10, and ρ=0.1, and R_i=100 for all nodes in all test networks. The parameters of the flocking parameters were α=0.90, V_i=10, SA=75, and SU=50. The simulation was run for T=1000 with a warm-up period of 50 for 100 random replications for each test network. Table 1 presents the results of the simulation experiments where Column A presents the mean results of 100 replications found using All Neighbors Mode. Column D% presents the mean percent difference between the All Neighbors and Delaunay Triangulation modes. Similary, Column G% presents the mean percent difference between All Neighbors and Gabriel Triangulation Mode.

The results in Table 1 show that Gabriel Triangulation mode provided the best performance in all cases. In the original flocking algorithm [4] with the all neighbors mode, multiple agents may be attracted to the same clusters of densely connected user nodes and not able to break out from them. Hence, these agents will be less likely to contribute to the overall connectivity of the network. Selecting interaction partners of agents based on the Gabriel triangulation encourages agents to collaborate implicitly. For example, if two agents are in close proximity and have many mutual topological neighbors, the rules of the Gabriel triangulation will prevent these agents to share many identical interaction partners. Thereby, the two agents can focus on supporting a different set of users.

TABLE I. The Results of the Simulation Study

(|U|,|A|)	A	D %	G%	(|U|,|A|)	A	D %	G%
(20,2)	23.2	-2.9	2.4	(40,2)	52.0	-0.4	4.0
(20,4)	28.8	-4.1	6.9	(40,4)	28.8	-0.5	8.4
(20,6)	34.3	-5.5	13.4	(40,6)	34.3	-0.2	12.4
(20,8)	40.2	-5.5	19.9	(40,8)	40.2	-0.1	16.5
(20,10)	46.3	-5.2	26.3	(40,10)	46.3	0.0	19.4
Avg.		-4.6	13.8	Avg.		-0.2	12.1
(30,2)	34.9	-1.4	3.5	(50,2)	71.9	0.4	2.8
(30,4)	28.8	-2.4	8.9	(50,4)	28.8	0.9	5.5
(30,6)	34.3	-2.3	14.7	(50,6)	34.3	0.8	8.0
(30,8)	40.2	-2.7	20.2	(50,8)	40.2	1.2	10.0
(30,10)	46.3	-1.8	25.5	(50,10)	46.3	1.2	11.5
Avg.		-2.1	14.6	Avg.		0.9	7.6

In this paper, the interaction partners of an agent are selected based on the Gabriel seems to establish sufficient but not excessive interconnections for agents to select their partners. Thereby, an agent movement is not heavily influenced by a group of its topological neighbors that are clustered tightly. Future research may include designing and testing more comprehensive agent behaviors and alternative ways of identifying interaction partners.

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