Mobility Prediction Clustering Algorithm for UAV Networking

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***Abstract*—In recent years, with the increasingly widespread application of unmanned aerial vehicle (UAV), the network technology of UAV has also caused for concern. In this paper, according to the background of related technologies of UAV, a mobility prediction clustering algorithm (MPCA) relying on the attributes of UAV is proposed. The dictionary Trie structure prediction algorithm and link expiration time mobility model are applied in this clustering algorithm to solve the difficulty of high mobility of UAV. The simulation shows that the reasonable clusterhead electing algorithm and on-demand cluster maintenance mechanism guarantee the stability of the cluster structure and the performance of the network.**

***Keywords:* Mobility prediction; Clustering algorithm; UAV; Dictionary Trie**

I. Introduction

UAV has been used widely in recent years. Although the UAV network is an Ad hoc network, the movement of the node is not haphazard and aimless, but according to some regular exercise, the direction will not change over time, the speed is almost maintained at a value around. The same situation occurs in aircraft, train and automobile transportation. Therefore, the study of UAV networking related technologies is of significance [1] [2].

II. Related Clustering Algorithms

Different clustering algorithms have different optimizations, such as minimum clusterhead election and maintenance overhead, maximum cluster stability, maximum node lifespan, etc. There are probably contradictions among these optimizations. In addition, lots of the optimizations and their combinations are an NP-hard problem. Thus, heuristic clustering algorithms are used to find sub-optimal solutions in common.

Lowest-ID (LID) algorithm [3] has the feature of simple calculation. If the cluster structure varies rapidly, the cluster maintenance overhead is relatively small. However, the clusterhead costs excessive resources so that the network lifespan is reduced.

Highest-degree (HD) or highest-connectivity algorithm [4] has the advantage of less cluster number to reduce the packet delivery delay. But when a cluster has too many nodes, the throughput of each node will decline sharply. Additionally when the node has high mobility, the clusterhead updating frequency will increase dramatically, which greatly increase the maintenance overhead.

In the algorithms described above, the clusterhead is selected by only one factor. The election of clusterhead needs to consider various factors and the network environment. In the weighted clustering algorithm (WCA) [5], a weight is calculated for each node as the suitability of becoming clusterhead. The node with the highest weight among the surrounding nodes will be chosen as a clusterhead. The weight includes node mobility, connectivity degree, energy consumption, etc. The weight of each node can use the following general formula:

$$w = c_1 M + c_2 \Delta + c_3 D + c_4 P \qquad (1)$$

where M is node mobility, Δ is connectivity degree, D is the total distance to its neighbors, and P is consumed battery power. Parameters, c_1, c_2, c_3 and c_4 are weighting factors. Their values are determined by the specific application and network environment and

$$c_1 + c_2 + c_3 + c_4 = 1 \qquad (2)$$

III. Mobility Prediction Clustering Algorithm

Because of some drawback of existing algorithms, in UAV networking environment, a new mobility prediction based on weighted clustering algorithm is proposed to form the mobility prediction clustering algorithm (MPCA).

A. Mobility Prediction Model Based on Link Expiration Time

Assuming all nodes in UAV networking in a free space propagation model, the signal strength is only associated with the propagation distance [6] [7], each node has the same ability to send signal and has the same spread range, while each node has been synchronized using NTP (Network Time Protocol) or GPS system. Thus, two nodes in the effective transmission range can be considered to maintain connection at any time.

The use of GPS system provides location and mobile information of nodes to calculate the link expiration time (LET) between any two nodes, as shown in Fig. 1. Two nodes, m and n, are within each other's transmission range. (x_m, y_m) and (x_n, y_n) are the coordinates of node m and node n respectively. v_m and v_n are the average speed of node m and node n. θ_m and θ_n ($0<\theta_m$, $\theta_n<2\pi$) are the mobile direction of the nodes. When the two nodes move along a straight line with their directions, the space between the two nodes after time t is the transmission radius r. If the nodes continue to move, the distance of them will become greater than the transmission radius r. The transmission link between them will interrupt.

$$r^2 = (a\,LET + b)^2 + (c\,LET + d)^2 \qquad (3)$$

where

$$a = v_m \cos\theta_m - v_n \cos\theta_n$$

$$b = x_m - x_n$$

$$c = v_m \sin\theta_m - v_n \sin\theta_n$$

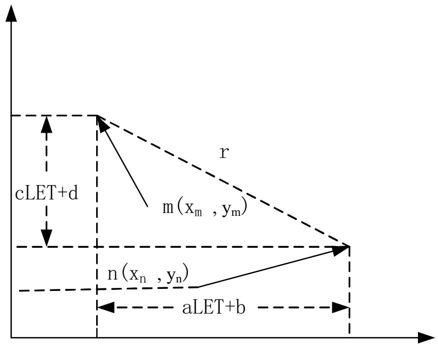

Figure 1. Diagram for calculation of LET

$$d = y_m - y_n$$

The time t is called the Link Expiration Time (LET) of the two nodes, which is

$$LET = \frac{-(ab+cd)+\sqrt{(a^2+c^2)r^2-(ad-bc)^2}}{a^2+c^2} \quad (4)$$

If $v_m = v_n$ and $\theta_m = \theta_n$, that is the speed and direction of movement of the two nodes are the same, then $LET \rightarrow \infty$, the two neighboring nodes can be always connected. If $LET < 0$, the two nodes are not connected.

B. Prediction Algorithm Based on Dictionary Trie Structure

Under normal circumstances, the clusterhead needs to be more stable than all the neighbors around it. The set $Neighbor_{m,t}=\{h_0,h_1,h_2,...h_{N-1}\}$ is used to present the N neighbors of node m at moment t. And $P(Neighbor_{m,t})$ is used to indicate the probability that the neighbor set will continue to maintain in the next period. Supposing the neighbor nodes are independent of each other, the probability can be written as:

$$P(Neighbor_{m,t}) = P(h_0)P(h_1)\ldots P(h_N) \quad (5)$$

where $P(h_i)$ ($0<i<N$) denotes the probability of node h_i existing in the set.

The dictionary trie structure is used for calculation of the probability, which has been successfully used in the field of data compression [8] [9]. In the algorithm, each trie structure represents the neighbor set of node m at any given moment. The input stream is a sequence of neighbor nodes. Each mobile node periodically sends "Hello" message to understand its neighbors. A mobile node determines its current neighbors by receiving "Hello" message in the last 2 * Broadcast_Interval which is the interval of "Hello" message broadcasting.

The trie structure is visited each Broadcast_Interval. Each trie node is used to record a neighbor set and the number of occurrences during the whole periodic visits. At the beginning, this structure contains only a root node. Visiting trie structure is to find a child trie node of current trie node which contains neighbor set. If the child trie node exists, its counting number will be increased by one. Otherwise, a new child trie node with the counting number of one will be inserted below the current trie node. And then return to the root of the trie structure. Therefore, the sequence from the trie root node to the new child trie node is the longest prefix found in the present trie structure

The trie structure is used to calculate the probability of (5). Supposing $\{h_0,h_1,h_2,...h_{s-1}\}$ as the latest neighbor set, the number of occurrences of each node in the set is counted by traversing all the nodes of the sub-tree in the trie structure. Also the values of all counters in the sub-tree are added up. Thus, the probability of the neighbor node h_i remaining in the set can be found. According to (5), the probability that the neighbor set will continue to maintain in the next period can be obtained.

C. Description of MPCA

The HD algorithm has been introduced in Section II, in which the node having the largest degree among adjacent neighbors is selected as clusterhead. Its goal is to improve network control ability and reduce the number of clusters. Its main drawback is that when nodes are highly mobile, the clusterhead updating frequency will rise sharply and cluster structure will change rapidly so that a large amount of maintenance overhead will be introduced.

The HD algorithm is combined with mobility prediction algorithm based on the trie structure in MPCA by considering the link expiration time. The new algorithm can reduce the instability of clustering. Moreover, the weight for each mobile node is defined as follows:

$$w_i=c_1*P(Neighbor_i)*d_i+c_2*avg\_d_i+c_3*LET_i \quad (6)$$

where, $P(Neighbor_i)$ is the probability of Neighbor set of node i maintaining the current status. d_i is connectivity degree of node i. avg_d_i is the average connectivity degree of all the neighbors of node i, which can be calculated easily from the information stored in the sub-trie structure. Coefficients c_1, c_2 and c_3 are weighting factors, indicating the relative importance of various factors. The more important factor is, the greater the corresponding weighting factor is. The greater the weight is, the more the number of neighbors is and the longer the neighbor set maintains. Therefore, the smaller virtual backbone can be achieved by choosing the node with the maximum weight among neighbor nodes as clusterhead so that the whole network will be more stable.

At the beginning of MPCA operation, nodes do not collect data into their trie structure. The clusterheads are selected based on HD algorithm and the LET values.

1) Clustering Stage

(a) Each node is given a globally unique node ID and its status is the initial state.

(b) Node's weight, $P(Neighbor_i)$, location, speed, direction and neighbor number are initialized. And neighbor list, clusterhead table and other information are also initialized.

(c) Each node places its own ID, current location, and mobile information into "Hello" message to broadcast to its one-hop neighbor nodes.

(d) According to information received from its neighbors, each node calculates its own weight.

(e) Each node with the largest weight in the neighbor set broadcasts "Clusterhead Announcement" message to its neighbors to declare itself as clusterhead. If the weight of the mobile node is not the biggest in the surrounding nodes, it will wait for the message from the node with larger weight. There may be the following two situations. If node *i* receives "Clusterhead Announcement" message from several nodes, it will join in clusterhead *v* which has longer LET with it. Then, node *i* broadcasts a "Neighbor Information" message to clusterhead *v* to join the cluster. The second situation is, if node *i* receives only "Cluster Request" message, node *i* will become a clusterhead and broadcast clusterhead information to its neighbor.

2) Maintenance of Clusters

In Ad hoc networks, node participation, departure and movement will result in changes in network topology, so the maintenance of network clusters is needed.

(a) Each node broadcasts "Hello" message to its neighbor nodes periodically.

(b) The neighbor list is inspected periodically every 2 * Broadcast_Interval.

(c) If a clusterhead disappears, its corresponding neighbors will not receive periodic messages, and be separate from it. If a member node does not receive periodic broadcasting from its clusterhead, it means the clusterhead has left the cluster. Similarly, if a clusterhead has not received periodic broadcasting from a member node, the clusterhead deletes the member from its member table.

(d) If a node does not belong to any cluster, it is an isolation node which periodically broadcasts neighbor information to find a new cluster to join. If a clusterhead allows it to join the cluster, it will send a "Clusterhead Announcement" message to the node.

(e) Although there will be no any two clusterheads within the transmission scope during initial clustering process, it can not guarantee that one clusterhead runs into the transmission scope of other nodes during the cluster maintenance process, which will result in clusters of competition. Thus, one of the clusterheads will give up its position of clusterhead.

(f) The node is allowed to constitute an independent cluster or join another cluster without the need for re-clustering in order to avoid frequent change of clusterheads. Moreover, the local change will not produce knock-on effect throughout the network.

(g) Re-clustering can only be initiated by the clusterhead. When a clusterhead finds other clusterheads more than a threshold L in its neighbors, re-clustering will be triggered.

IV. ALGORITHM IMPLEMENTATION AND SIMULATION

This algorithm is implemented and simulated in NS2 environment with range of 1000 * 1000 units and simulation time of 1000s. After running at their original constant speeds for some distances, the nodes change their speed, which simulates the mobile node in normal scene. The coefficients, c_1, c_2 and c_3, in (6) are set 0.7, 0.1, 0.2, and L=6, while the broadcasting interval of neighbor information message is 1s.

In the following simulation process, the MPCA algorithm is compared with LID, HD and WCA algorithms. The right value of WCA is set as c_1= 0.7, c_2= 0.2, c_3= 0.1, c_4= 0. That is the energy factor is not considered in WCA.

The flow of data between nodes is set randomly by the Cbrgen tool. The Cbr packet is 512B of size and is sent per second. The network bandwidth is 2M. The transmission radius varies according to simulation environment. The ground reflection model is used as wireless channel model, while IEEE 802.11 DCF protocol is used in MAC layer.

Simulation scene settings are randomly generated. Each simulation generates a total of 100 types of network topology and the final data are the average value.

A. *Number of Clusters*

The number of clusters formed in the different algorithms is compared by setting different node signal coverage. In the simulation, the maximum speed of each node is 20units/s and the number of clusterheads is counted every 10s.

Fig.2 and Fig.3 show the simulation results at node signal coverage of 100 units and 200 units respectively.

In Fig.2, it can be found that with the increase in the number of nodes, the number of clusterheads is constantly increasing. The number of clusterheads of HD algorithm is much lower than that of other algorithms, while the MPCA algorithm is more reasonable because of consideration of both node connectivity and mobility prediction.

Fig.3 shows that, with the increase of the transmission radius, the number of clusterheads will be relatively reduced. MPCA algorithm performance is close to HD algorithm. The number of clusters of MPCA algorithm is still more than that of HD algorithm, because the MPCA considers the link between nodes and weakens the role of the connectivity degree.

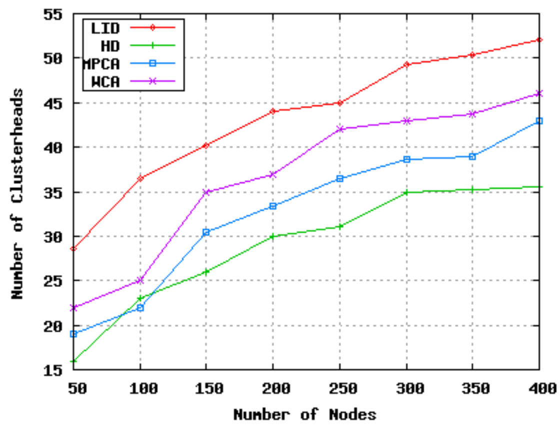

Figure 2. Number of cluster heads vs number of nodes at node

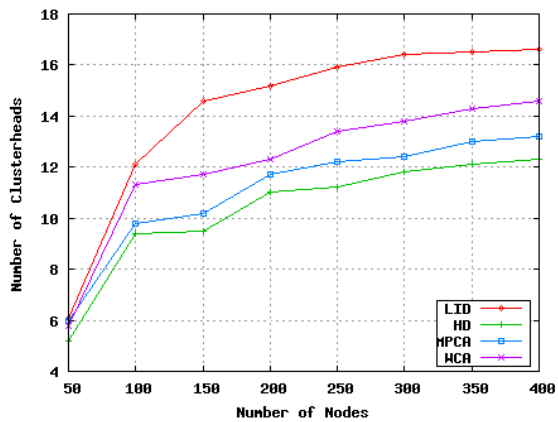

Figure 3. Number of cluster heads vs number of nodes at node transmission range of 200 units

B. Duration of Clusterhead

The duration of clusterhead is analyzed with the increase of the maximum speed of nodes. The number of nodes is 50 and the duration is the average time of all the clusterheads.

Fig.4 and Fig.5 show that with the increase of node mobility, the performance of MPCA algorithm is better than that of other algorithms. This is due to use a more reliable mobility prediction model and the trie-based structure prediction algorithm, thus ensuring a more stable cluster structure.

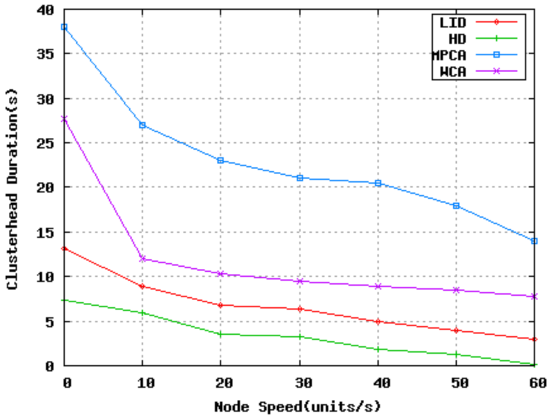

Figure 4. Duration of cluster heads vs node speed at node transmission range of 200 units

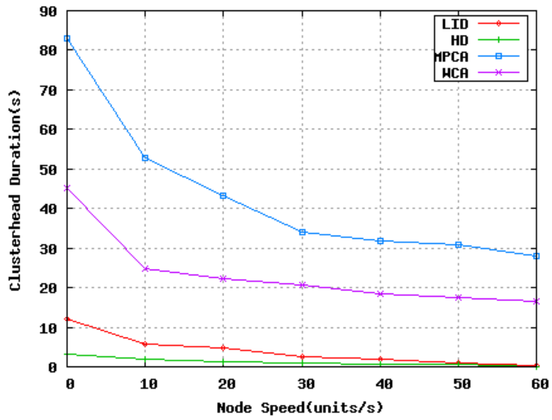

Figure 5. Duration of cluster heads vs node speed at node transmission range of 300 units

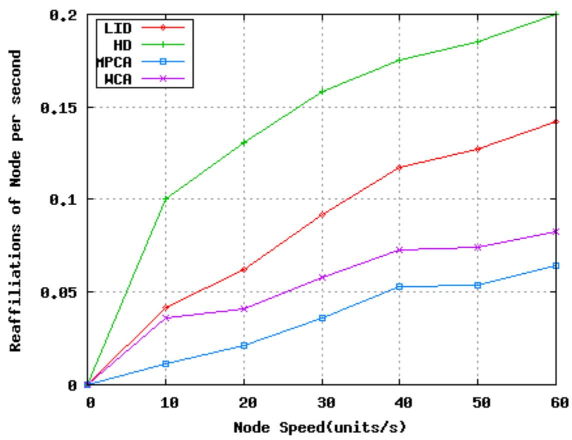

Figure 6. Reaffiliation frequency vs node speed at node transmission range of 200 units

C. Reaffiliation Frequency

The simulation uses 50 nodes whose movement range is still 1000 * 1000 units.

In Fig.6, with the increase of the node mobility, the reaffiliation frequency becomes higher. The nodes are more likely to leave their clusterhead and attach to a different cluster. Compared with the other algorithms, MPCA algorithm shows lower reaffiliation frequency. In MPCA algorithm, even other clusterheads appear in the vicinity of a node, it will not change its clusterhead list. Only when a node loses contact with the original clusterhead, it can enter other cluster.

V. Conclusion

The proposed MPCA algorithm for UAV networking environment is a stable prediction clustering algorithm. The simulation experiments show that the algorithm has a certain rationality and stability and improves the network performance.

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