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A Stable Clustering Scheme by Prediction of the Staying Time in a Cluster for Mobile Ad Hoc Networks

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***Abstract*—We propose a new clustering scheme for Mobile Ad hoc NETworks (MANETs), which can maintain a stable clustering structure by predicting the staying time for a cluster and selecting an optimal clusterhead (CH) which a node affiliates with. In the proposed scheme, when there are multiple CHs in the node's one hop neighbors at the initial clustering set-up or the node's movement to the outside of the transmission range of its CH, each node predicts the time when it would stay in the transmission range of a CH by using past position information of itself and the CH, and selects the CH with the maximum predicted staying time within neighbor CHs, and affiliates with the CH. Therefore, each node can stay in the same cluster for a long time. In addition, the proposed clustering scheme normalizes the system parameters which are used in the weight value calculation. The simulation results show that the proposed clustering scheme can reduce the average numbers of reaffiliations and control overheads compared with Distributed Weighted Clustering Algorithm (DWCA).**

I. Introduction

In recent years, the rapid growth of wireless communication technologies has been leading us to the future ubiquitous society. The Mobile Ad hoc NETwork (MANET) [1] is expected to be one of the most essential techniques in the ubiquitous society. Since MANET does not need any infrastructure for establishing a network, and is a network consisted of the wireless device only, it expects to use in disaster, in military, and at the event site. However, since MANET does not have a base station which intensively controls wireless devices and builds a network consisted of them only, the number of control packets increases when network scale extends by increasing the number of devices. Then, the clustering technology that reduces the communication overhead by dividing and hierarchizing the network has been proposed [2]. Hierarchization of the network is achieved by dividing into two or more areas that are called clusters, and separating the communication among nodes in a cluster and that among clusters. One node in a cluster becomes a leader (clusterhead: CH) and it performs the management of nodes in its cluster and the communication between clusters. Other nodes in the cluster become members of CH. The advantages of clustering are follows: (1) the spatial reuse of wireless bandwidth, (2) the flexible response to topology changes by node movement, (3) the reduction of control packets in routing. Because of above reasons, a lot of clustering algorithms have been proposed in MANETs [3]-[7].

As the clustering scheme in MANETs, Distributed Weighted Clustering Algorithm (DWCA) , which reduces the control overheads by exchanging the weight values and electing a CH within one hop neighbor nodes only, has been proposed[4]. In DWCA, each node calculates a weight value based on the node-degree, node speed, the sum of distances with all its neighbors, and battery power, and then, the node with the smallest weight value within one hop neighbors is elected as a CH. If a node moves into a region that is not covered by any CH, it declares itself as a CH, resulting in the reduction of unnecessary control packets due to reclustering through the network. Moreover, since a CH resigns the role of CH when it consumes more battery power than the threshold value, DWCA can avoid increasing the load of a CH. However, when a node has multiple CHs in its one hop neighbors at the initial clustering set-up or the node's movement to the outside of the transmission range of its CH, since the node selects a CH based on the weight value of neighbor CHs, it may select an inadequate CH. In addition, since system parameters are not normalized for the weight value calculation, the weight value depends on the parameter with large value.

In this paper, we propose a new clustering scheme for MANETs, which can maintain a stable clustering structure by predicting the staying time for a cluster and selecting an optimal CH which a node affiliates with. In the proposed scheme, when there are multiple CHs in the node's one hop neighbors at the initial clustering set-up or the node's movement to the outside of the transmission range of its CH, each node predicts the time when it would stay in the transmission range of a CH by using past position information of itself and the CH, and selects the CH with the maximum predicted staying time within neighbor CHs, and affiliates with the CH. Therefore, each node can stay in the same cluster for a long time. In addition, the proposed clustering scheme normalizes the system parameters which are used in the weight value calculation. The simulation results show that the proposed clustering scheme can reduce the average numbers of reaffiliations and control overheads compared with DWCA.

II. Conventional Scheme

DWCA achieves distributed clustering set-up and extends lifetime span of the system. DWCA reduces the control overheads by exchanging the weight values and electing a CH within one hop neighbor nodes only, con-

sisting of the clustering set-up and clustering maintenance phase.

A. Clustering set-up

Initially, each node broadcasts a Hello message which consists of its ID and position value. Each node builds its neighbor list based on the received Hello messages. Next, each node calculates a weight value which is used to elect the CHs. The following is the calculation procedure of the weight.

1) Find degree, d_v, which is the number of neighbors of a node v.
2) Compute the degree-difference, $\Delta_v = |d_v - \delta|$, for node v, where δ is a pre-defined threshold for the number of nodes that a CH can handle ideally.
3) Compute the sum of the distances, D_v, with all its neighbors v', as
$$D_v = \sum dist(v, v') \tag{1}$$
4) Compute the measure of mobility, M_v, which is the running average of the speed until the current time T.
$$M_v = \frac{1}{T}\sum_{t=1}^{T}\sqrt{(X_t - X_{t-1})^2 + (Y_t - Y_{t-1})^2} \tag{2}$$
where (X_t, Y_t) and (X_{t-1}, Y_{t-1}) are the coordinates of the node v at time t and $(t-1)$, respectively.
5) Compute the consumed battery power, E_v.
6) Calculate the combined weight W_v for node v,
$$W_v = w_1\Delta_v + w_2 D_v + w_3 M_v + w_4 E_v \tag{3}$$
where w_1, w_2, w_3 and w_4 are the weighting factors for the corresponding system parameters and sum of the weighting factors equals 1.

After calculating of the weight value, each node broadcasts W_Info message which contains its ID and weight value to its one hop neighbors. After receiving the W_Info messages from the neighbors, each node builds a list Γ, which contains the IDs and the weights of itself and its neighbors. The list Γ can be defined as follows: $\Gamma = \{(k, W_k) : k \in \{IDs\ \ of\ \ neighbors\} \cup \{my_id\}\}$. After building Γ, if own weight value is the smallest in Γ, the node declares itself as a CH and broadcasts $Cluster$ message, otherwise, the node associates with a CH with the smallest weight value among its neighbor CHs as a ordinary node.

B. Clustering maintenance

The second phase is the clustering maintenance. There are two situations that invoke the clustering maintenance, one is the situation1 when a node moves out of the transmission range of its CH, and the other is the situation2 when a CH consumes the battery excessively.

1) Node's movement to the outside of the transmission range of its CH: When an ordinary node moves out of the transmission range of its CH, it is necessary for it to find a new CH to affiliate with. When a node moves out of the transmission range of its CH, it broadcasts a $Find_CH$ message which contains its ID. If any CH receives the $Find_CH$ message, it replies a CH_Ack message which contains its ID and its weight to the node. It selects a CH with the smallest weight value as a new its CH based on the received CH_Ack messages. Then it sends a $Join_CH$ message which contains its ID and its CH ID to the selected CH, and hands over to the CH. If it does not receive any CH_Ack message within a given time period, it declares itself as a CH by broadcasting a $Cluster$ message which contains its ID and its CH ID.

2) Excessive battery consumption at a CH: Each CH updates the amount of consumed battery power when it sends and receives packets. If a CH has consumed more battery power than a pre-defined threshold value, the CH resigns its role as CH and becomes an ordinary node. If a CH has consumed more battery power than the threshold value, it broadcasts CH_Resign message which contains its ID. It is necessary that all the nodes in the cluster determine a new CH. Each node calculates its own weight value, and broadcasts the weight using a W_Info message. Then each node builds a new list Γ, and executes the cluster set-up algorithm. After determining a new CH, other nodes affiliate with the new CH.

C. Problems

In DWCA, since each system parameter such as node-degree, no, etc. is not normalized for the weight value calculation, the weight value depends on the parameter with large value. In addition, when a node has multiple CHs in its one hop neighbors at the initial clustering set-up or node movement to the outside of the transmission range of its CH, since the node selects a CH based on the weight value of neighbor CHs, the node may select an inadequate CH. Since the weight value is used to judge whether a node is more optimal as a CH than the neighbor nodes, it is not necessarily the case that the CH with the smaller weight value is the most optimal CH for a node to affiliate with. For example, the distance between a node and the CH with the smallest weight value for the node may be long, and the node may move out of the transmission range of the CH with the smallest weight value as soon as it affiliates with the CH if the direction of the movement of the node to the CH is mutually opposite. When the node cannot select the optimal CH which it affiliate with, the control overheads by reaffiliations and reclustering increases.

III. Proposed Scheme

We propose a new clustering scheme for MANETs, which can maintain a stable clustering structure by predicting the staying time for a cluster and selecting an optimal CH which a node affiliates with when there are multiple CHs in the node's one-hop neighbors at the initial clustering set-up or the node's movement to the outside of the transmission range of its CH. In addition, the proposed clustering scheme normalizes the system parameters which are used in the weight value calculation. The details of the proposed clustering scheme are described as follows.

A. The selection scheme of an optimal CH which a node affiliates with

In the proposed scheme, when a node has multiple CHs in its neighbors at the initial clustering set-up or the node's movement to the outside of the transmission range of its

CH, the node predicts the time when it would stay in the transmission range of a CH and selects a CH with the maximum predicted staying time. For prediction of the staying time, each node uses the own relative velocity vectors to the neighbor CHs calculated by the past position information of itself and neighbor CHs. The details of the selection scheme of an optimal CH are described as follows.

1) Storage of position information: First, each node stores the position information of itself and neighbor CHs by Hello messages. Each node stores its ID, its weight value, its status (CH, ordinary node, or unknown), and its position information in Cartesian coordinates (x, y) in a Hello message, and broadcasts it periodically. Each node has the one-hop neighbor node table which stores the information of one-hop neighbor nodes gotten by Hello messages. Each node stores the information of Hello message of past n seconds, and removes the information other than the information in the past n seconds. In addition, each node stores the own position information of past n seconds for understanding the transition of its position information in the past.

2) Calculation of relative velocity: Next, each node calculates the own relative velocity vectors to the neighbor CHs by using the position information of itself and the neighbor CHs. Each node calculates the average movement direction vectors of the neighbor CHs based on the position information of the CHs gotten by Hello messages. The node calculates $n-1$ $\overrightarrow{C_tC_{t+1}}$ using Eq. (4) based on Hello message information of past n seconds.

$$\overrightarrow{C_tC_{t+1}} = (x_{t+1} - x_t, y_{t+1} - y_t) \qquad (t = 1, 2, ..., n-1) \quad (4)$$

And, the node calculates the average movement direction vector of the CH by calculating the average of $n-1$ $\overrightarrow{C_tC_{t+1}}$ as shown in Eq. (5).

$$\overrightarrow{v} = \frac{1}{n-1}\sum_{t=1}^{n-1}\overrightarrow{C_tC_{t+1}} \quad (5)$$

Moreover, the node calculates the own average movement direction vector using Eq. (5) based on own position information. After that, each node calculates the own relative velocity vector to the CH $\overrightarrow{v}_{A\to B}$ based on the average movement direction vector of own node $\overrightarrow{v}_B$ and that of the CH $\overrightarrow{v}_A$ using Eq. (6).

$$\overrightarrow{v}_{A\to B} = \overrightarrow{v}_B - \overrightarrow{v}_A \quad (6)$$

Each node calculates the own relative velocity vectors to the CHs with respect to all neighbor CHs using Eq. (6).

3) Prediction of own movement direction to the CH: Next, each node judges whether own node is moving towards the CH or leaving away from the CH by using the own relative velocity vector to the CH. Fig.1 shows an example of prediction of own movement direction to the CH. Here, own node ID is B and CH ID is A. To judge whether own node is moving towards the CH or leaving away from the CH, we use the angle formed by the own relative velocity vector to the CH $\overrightarrow{v}_{A\to B}$ and the straight line vector pulled from own node to the CH $\overrightarrow{BA}$ as the criterion for judgment. We use the inner product as the criterion of judgment and it is described as follows.

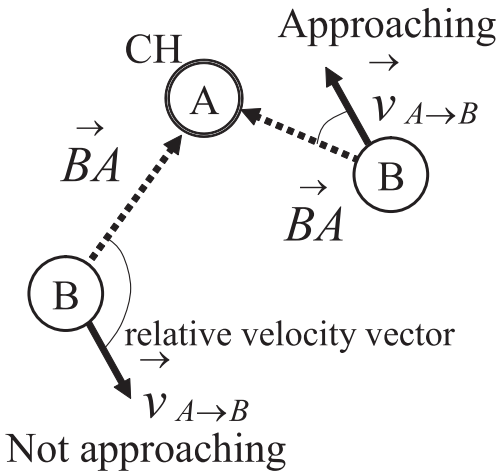

Fig. 1. The example of prediction of own movement direction to the CH.

- If $\overrightarrow{v}_{A\to B} \cdot \overrightarrow{BA} \geq 0$Cnode B is moving towards the CH A
- If $\overrightarrow{v}_{A\to B} \cdot \overrightarrow{BA} < 0$, node B is leaving away from the CH A

4) Prediction of the time when the node would stay in the transmission range of the CH: After that, each node predicts the time when it would stay in the transmission range of the CH T_{stay} by using the own relative velocity vector to the CH. The calculation method of the predicted staying time T_{stay} is shown below.

1) Node B is moving towards CH A
Fig.2 and Eq. (7) shows the calculation method of the predicted staying time T_{stay} when node B is moving towards CH A. By considering node B's relative velocity vector to CH A in Fig.2, CH A can be regarded as the fixed. Therefore, the predicted staying time T_{stay} is shown as

$$T_{stay} = \frac{Y+Z}{|\overrightarrow{v}_{A\to B}|} = \frac{\sqrt{R^2 - X^2} + \sqrt{AB^2 - X^2}}{|\overrightarrow{v}_{A\to B}|}. \quad (7)$$

2) Node B is leaving away from CH A
Fig.3 and Eq. (8) shows the calculation method of the predicted staying time T_{stay} when node B is leaving away from CH A. This case is the same as case 1. The predicted staying time T_{stay} is shown as

$$T_{stay} = \frac{Z}{|\overrightarrow{v}_{A\to B}|} = \frac{\sqrt{R^2 - X^2} - \sqrt{AB^2 - X^2}}{|\overrightarrow{v}_{A\to B}|}. \quad (8)$$

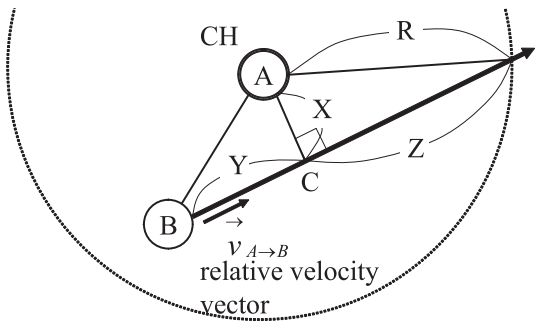

Fig. 2. The calculation method of the predicted staying time when the node B is moving towards the CH A.

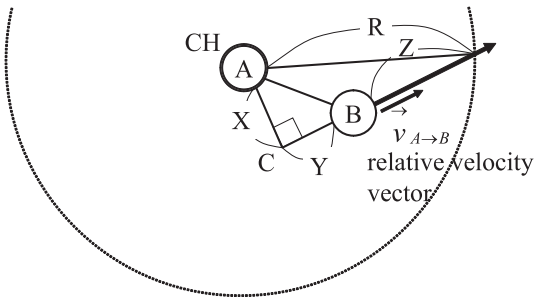

Fig. 3. The calculation method of the predicted staying time when the node B is leaving away from the CH A.

5) Selection of a CH which the node affiliates with: Each node selects a CH which it affiliates with by using the predicted staying time T_{stay}. When a node has multiple neighbor CHs, it selects the CH with maximum T_{stay} as a CH, and affiliates with the CH. Therefore, in the proposed scheme, each node can stay in the selected CH for a long time and the proposed scheme can reduce the number of reaffiliations by handover and maintain stable clustering structure.

B. Normalization of the system parameters used in the weight calculation

In the proposed scheme, by normalizing the value of each system parameter in range of 0.0‘1.0, the fairness of each parameter can be achieved. The system parameters used in the proposed clustering scheme and the method of normalization of each parameter are described as follows.

1) Parameters used in the proposed scheme: In the proposed scheme, the degree difference Δ_v, consumed battery power E_v, and node speed M_v are used in weight calculation as well as in DWCA. In addition, it uses the average of the absolute value of the neighbors' relative velocity vector to own node R_v in place of the sum of distances with all its neighbors D_v. The smaller value of R_v is, the smaller neighbors' mobility to own node is, and the node with small R_v is more optimal as a CH. Since we aim to form the stable cluster structure such that ordinary node can stay in the transmission range of the CH for a long time, we think that R_v is more optimal parameter than D_v.

2) Normalization of each parameter: To normalize the parameters, each parameter is divided by the maximum value of it. The normalized parameters Δ_v^{nl}CE_v^{nl}CM_v^{nl}Cand R_v^{nl} are shown below.

- $\Delta_v^{nl} = \Delta_v / |N - \delta|$
  , where N is the number of nodes in the network.
- $E_v^{nl} = E_v / Initial_battery_power$
- $M_v^{nl} = M_v / max_speed$
- $R_v^{nl} = R_v / (max_speed * 2)$

3) Weight calculation: Weight calculation is executed by the same method as DWCA. The weight W_v is calculated by using the Eq. (9) as

$$W_v = w_1 \Delta_v^{nl} + w_2 R_v^{nl} + w_3 M_v^{nl} + w_4 E_v^{nl} \qquad (9)$$

, where w_1, w_2, w_3 and w_4 are the weighting factors for the corresponding system parameters and sum of the weighting factors equals 1. The proposed scheme elects the CHs by using the weight values as shown in Eq. (9). After electing the CHs, each node selects an optimal CH by using the selection scheme of an optimal CH as shown in section Ⅲ.A.

IV. Performance Evaluation

We evaluate the performance of DWCA and the proposed clustering scheme in terms of the average number of reaffiliations and the average number of control overheads. Table I shows the simulation parameters. And the values of weighing factors used in the weight calculation in DWCA and the proposed scheme are set to below: $w_1 = 0.2$, $w_2 = 0.35$, $w_3 = 0.4$ and $w_4 = 0.05$. Moreover, the number of position information gotten by Hello message n is set to 2.

A. The average number of reaffiliations

We evaluate the average number of reaffiliations. Here, the average number of reaffiliations shows the number of which a node changes the CH by handover per time. Fig. 4 shows the average number of reaffiliations versus the node speed. It is found from Fig. 4 that the proposed scheme can reduce the average number of reaffiliations regardless of the node speed and the number of nodes. The reason is that in the proposed scheme each node can stay in the same cluster for a long time by predicting the time when it would stay in the transmission range of the CH and selecting an optimal CH within the neighbor CHs. Moreover, the faster the node's maximum speed is, the more improvement the performance of the proposed schemes compared with DWCA is. Therefore, the proposed scheme is effective even if the node speed is fast.

B. The average number of control overheads

We evaluate the average number of control overheads. Here, control overheads is the overheads by sending Hello message, W_Info message, $Cluster$ message, $Find_CH$ message, CH_Ack message, $Join_CH$ message, and CH_Resign message. Fig. 5 shows the average number of control overheads versus the node speed. It is found from Fig. 5 that the proposed scheme can reduce the average number of control overheads. The reason is that the proposed scheme reduces the number of reaffiliations since each node predicts the time when it would stay in the transmission range of the CH and selects an optimal CH within the neighbor CHs. By the reduction of the number of reaffiliations, nodes can reduce the control overheads induced by handover. In addition, the proposed scheme can keep the control overhead low even if the node speed is fast and the number of nodes increases. The reason is that the

TABLE I
Simulation parameters.

Field area	500m×500m
Maximum speed	$v = 5 - 25$m/s
node speed distribution	$0 - v$: uniform distribution
Simulation time	1000sec
Number of nodes	$25, 50, 75$
Transmission power	0.032W
Receiving power	0.02W
Idle power	0.001W
Initial battey power	100W
Ideal degree for cluserhead	5
Communication range	130m
Movement pattern of nodes	random waypoint

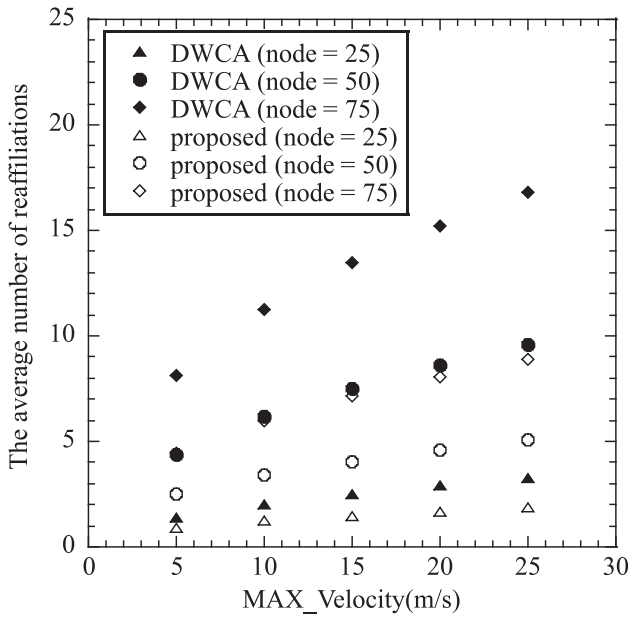

Fig. 4. The average number of reaffiliations versus the node speed.

exchange of weight information can reduce at the cluster maintenance since the weight value is contained in Hello message in the proposed scheme except the reduction of control overheads by handover. Therefore, the proposed scheme is effective regardless of the node speed and the number of nodes.

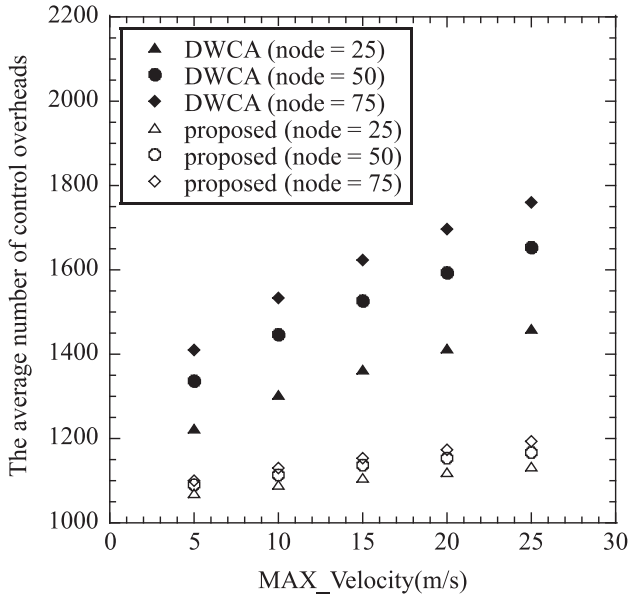

Fig. 5. The average number of control overheads versus the node speed.

V. Conclusion

In this paper, we have proposed a new clustering scheme for MANETs, which can maintain a stable clustering structure by predicting the staying time for a cluster and selecting an optimal CH which a node affiliates with. In the proposed scheme, when there are multiple CHs in the node's one hop neighbors at the initial clustering set-up or the node's movement to the outside of the transmission range of its CH, each node predicts the time when it would stay in the transmission range of a CH by using past position information of itself and the CH, and selects the CH with the maximum predicted staying time within neighbor CHs, and affiliates with the CH. Therefore, each node can stay in the same cluster for a long time. In addition, the proposed clustering scheme normalizes the system parameters which are used in the weight value calculation. The simulation results show that the proposed clustering scheme can reduce the average numbers of reaffiliations and control overheads compared with DWCA.

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