Research on Weighted Clustering Algorithm for Ad Hoc Networks Based on Topology Correlation

Luchao Shan, Luyong Zhang
School of Information and Communication Engineering, Beijing University of Posts and Telecommunications, Beijing 100876, China
shan_luchao@126.com

Abstract. In order to improve the clustering performance of wireless networks, an improved multi-parameter weighted clustering algorithm named TCWCA was proposed. The algorithm takes into account the calculation factors of node degree, inter-node distance, node mobility, node energy, and the increment of network topology association in the clustering process. In addition, the algorithm applies the increments of regional topology association of network nodes to the process of calculating weighting factors. The simulation results show that the algorithm has better clustering performance and improves the stability of the network clustering structure.

1. Introduction

Ad Hoc network is a special network composed of wireless nodes dynamically. In Ad Hoc networks, the core of clustering algorithm is to make mobile nodes with similar node performance into a cluster unit[1-2]. Within each cluster unit, the node with the best performance in the unit is selected as the cluster head, which is responsible for communication between cluster units and within cluster units.

Ad Hoc networks generally adopt the "cluster-common node" structure pattern shown in Figure 1. In wireless network clustering algorithm[3], the core is the cluster head election mechanism. At present, many clustering algorithms take into account the information of node degree and node energy, but most of them do not consider the topological correlation, nor do they consider the impact of the
relative proportion of node degree and energy on cluster head election in different topological regions[3-4].

2. Typical Clustering Algorithms for Ad Hoc Networks

Many clustering algorithms have been proposed to improve the performance of Ad Hoc networks in the construction and maintenance stage. The core of clustering algorithm is to generate and maintain a stable cluster structure while maintaining a small network overhead. Different network clustering algorithms have different emphasis on cluster head election strategies, including the minimum ID-based clustering algorithm, the minimum mobility-based clustering algorithm, and the comprehensive weighted clustering algorithm[3-4].

2.1. Clustering Algorithm Based on Minimum Node ID

Minimum ID clustering algorithm is a heuristic algorithm based on node ID. In this algorithm, each node will have a unique ID number. Each node sends Hello messages periodically to continuously obtain the ID number of its neighbor nodes[4]. In the neighboring nodes, the node with the smallest ID number is selected as the cluster head node, and the neighbor node with one hop from the cluster head node becomes the cluster member node of the cluster head. Nodes within the coverage of multiple cluster heads become gateway nodes, thus completing the clustering process of the network.

Minimum ID clustering algorithm has the advantages of low implementation difficulty, low computational complexity and fast convergence speed. However, the disadvantage of this algorithm is that the overall network overhead is large and the network topology stability is low[5]. Figure 2 shows the cluster structure after the implementation of the minimum ID clustering algorithm.

2.2. Clustering Algorithm Based on Minimum Mobility

The stability of network topology structure is affected by the mobility of nodes[6]. The clustering algorithm based on minimum mobility considers the mobility characteristics of nodes. The mobility formula of node a relative to node B is defined as follows:

\[ M_b(a) = 10 \log \frac{R_a P_a^{b-a}}{R_a P_a^{b-b}} \]

Among them, \( R_a P_a^{b-a} \) and \( R_a P_a^{b-b} \) are the first and second power values transmitted to node b by node a respectively. The factor \( M_b(a) \) is calculated by the above formula. If \( M_b(a) \) is greater than zero, it indicates that node a and node b are close to each other. If \( M_b(a) \) is less than zero, it indicates that node a and node b are far away from each other.

The mobility of nodes in network topology relative to other neighboring nodes is defined as follows:

\[ \bar{M}_b = \frac{\sum_{i=1}^{m} |M_b(a_i)|}{m} \]

In the above formulas, \( m \) denotes the number of all neighbor nodes of node b, and \( a_i \) denotes the first i neighbor node of node b. The calculated results \( \bar{M}_b \) represent the mobility of node b. The
smaller the $M_b$ is, the weaker the mobility of this node is, and it is more suitable to serve as cluster head.

2.3. Comprehensive Weighted Clustering Based on Key Factor

Comprehensive weighted clustering WCA algorithm considers the influence of multi-aspect node information in network topology. In the cluster head election process, each node is assigned corresponding weights, and cluster heads are generated by comparing weights. Network nodes with smaller weights are preferred to cluster heads. When calculating the weights of each node, the corresponding weighting parameters will be set, taking into account the node degree, residual energy, node mobility and other factors. And this algorithm can adjust the weighting parameters adaptively according to different network environments and states, so that the algorithm has strong adaptability. The cluster structure after the algorithm is executed is shown in Figure 3.

In the process of cluster head election, WCA algorithm takes into account the node degree, residual energy and mobility of network nodes. This makes the process of cluster head election and maintenance more reasonable[6-7]. On the other hand, because many factors (such as residual energy, mobility, etc.) of the network nodes will change with the network state, the stability of WCA algorithm based on comprehensive weighted clustering is not high, and the network overhead is also large. Moreover, this algorithm does not take into account the application of relative performance advantages of cluster head nodes and common nodes in the unit area of the network in cluster head continuation and cluster head re-election.

3. Weighted Clustering Based on Topological Association

Based on the on-demand weighted clustering algorithm, this algorithm introduces the increment of topological association between cluster head nodes and inter-cluster nodes in the process of cluster head election. This makes it easier for cluster head nodes/inter-cluster nodes with higher relative performance in specific areas of network topology to continue to act as cluster head/be elected as cluster head nodes, thus improving the stability of network clustering structure.

3.1. The Thought of The Algorithm in This Paper

The TCWCA algorithm proposed in this paper is an improved algorithm based on the WCA algorithm. Each node is given a weight, and the cluster head is selected by comparing the weights to generate the whole cluster[8]. In the calculation of weights, the connectivity, average relative distance, mobility, energy and topological relevancy of each node are considered comprehensively.

In the weight calculation formula, the node degree ratio and energy ratio of cluster head nodes and common nodes in a specific topological region are calculated. Through reasonable control parameters, the proportion of node degree and energy of cluster head node and common node in a unit area can affect the weight of a node. That is to say, for cluster head nodes and cluster member nodes, by introducing the increment of topological correlation, the cluster head nodes and cluster member nodes
with higher proportion of node degree and node energy in a unit area have certain advantages of
cluster head continuation or election. Thus, the network topology stability can be improved. Fig. 4 is
the schematic diagram of this algorithm.

Fig.4 TCWCA algorithm schematic diagram

In the process of cluster head election, the cluster head is selected according to the weight of each
node, and the node with smaller weight becomes the cluster head first. When calculating the weights
of nodes, TCWCA algorithm takes into account the connectivity, average relative distance, mobility
and topological correlation of nodes in the network. In order to increase the stability of cluster
structure and reduce the number of cluster head updates, this algorithm introduces a certain increment
for cluster head/cluster node members with higher relative energy and relative node degree to reduce
their weights, which increases the possibility of being elected as cluster head in the process of cluster
head election. The weights of each node can be calculated by a general formula considering various
factors[9]. The formula for calculating the weights of each node is as follows:

\[
W_n = \frac{1}{a + c + [(1 - k(\alpha_n + \beta_n))(b + d)]} \left( a \cdot D_n + [(1 - k(\alpha_n + \beta_n))b \cdot S_n + c \cdot M_n + [(1 - k(\alpha_n + \beta_n))d \cdot E_n] \right)
\]

In the above formula, \(W_n\) represents the weight factor of each node \(n\), which is used to indicate the
degree to which the node is suitable for acting as the cluster head. The smaller the weight of the node
is, the more suitable it is to act as the cluster head. \(D_n\) denotes the connectivity factor of the node, \(S_n\)
denotes the average distance factor of the node, and \(M_n\) denotes the mobility factor of the node. In
order to improve the performance of clustering algorithm and ensure the high efficiency of cluster
head election, and to consider the performance continuity of cluster head nodes and the relative
performance of common nodes in the process of cluster head election, this algorithm introduces the
increment of topological correlation \(\alpha_n\Delta_1, \beta_n\Delta_2\) into the weight factor formula of each node. Among
them, the coefficients \(\alpha_n\) and \(\beta_n\) before \(\Delta_1\) and \(\Delta_2\) are discrete variables, and their values are related
to the division of the relative topological region where the current node is located. Definition \((1 - k(\alpha_n + \beta_n))\) is a feedback regulator, which can be used to calculate the weights of node average
distance factor \(S_n\) and node energy factor \(E_n\).

3.2. The Design of Weighted Parameters for Improved Algorithms

(a) Node Degree Factor \(D_n\)

Each node in the network topology gets its own degree information by periodically interacting
Hello messages. The node degree of each node is defined as:

\[
d_n = |N(n)| = \sum_{n' \in N(n), n' \neq n} \{\text{dist}(n, n')\} < T
\]
Among them, \( T \) is the intersection of network topology partition area and node coverage area. The nodal degree factor \( D_n \) is calculated by \( D_n = |d_n - \delta| \). The difference between the degree of each node \( n \) and the optimal cluster member number \( \delta \) is calculated.

(b) Node spacing factor \( S_n \)

The average distance between each node \( n \) and all neighboring nodes in network topology is defined as:

\[
S_n = \frac{\sum_{n \in N} \{dist(n, n')\}}{d_n}
\]

In the above formula, \( \sum_{n \in N} \{dist(n, n')\} \) is the sum of the distance between the node and all its neighbors, and \( d_n \) is the node degree of the node.

(c) Node mobility factor \( M_n \)

In the process of weight calculation, the mobility of network nodes is mainly used to describe the stability of clusters. The smaller the mobility of nodes is, the more stable the cluster structure will be. On the contrary, the more unstable the cluster structure will be.

The specific calculation method of node mobility \( M_n \) is that the node receives Hello messages in succession and defines the received Hello messages as the total time. In addition, each Hello message transmitted contains a specific neighbor node record table, which is used to record all neighbor node information of the current network node[8]. The calculation formula is as follows:

\[
M_n = \sum_{i=1}^{n} W_i * D_n^x
\]

\[
W_i = \frac{1}{M_{x_i}} / \sum_{j=1}^{n} (1/M_{x_j})
\]

\( M_{x_i} \) is the mobility index of the node \( X_i \) and it is included in the "Hello" information.

(d) Node Energy Factor \( E_n \)

The energy consumption of node \( n \) is:

\[
E_n = \sum_{i=1}^{L} E_1 M_{n_i} T_{n_i} + E_2 T_{n_0}
\]

Whereas, \( L \) represents the total number of times that node \( n \) acts as cluster head node in the process of cluster execution. \( M_{n_i} \) denotes the number of cluster members when the node \( n \) is the cluster head for the first \( i \) time. \( T_{n_i} \) denotes the time when a node maintains its cluster head for the first \( i \) time. \( E_1 \) represents the energy consumption per unit time of cluster head node in unit topology area relative to each ordinary node. \( E_2 \) represents the energy consumption per unit time of node \( n \) in unit topology area as ordinary node. \( T_{n_0} \) is the total duration of node \( n \) as a normal node. Assuming that the initial energy of the node is certain, the smaller the \( E_n \) is, the more residual energy of the node is.

(e) Topological Association Increments of Cluster Heads and Cluster Nodes

In TCWCA algorithm, \( \Delta_1 \) and \( \Delta_2 \) represent the incremental constants of topological association, and the variables \( \alpha_n \Delta_1 \) and \( \beta_n \Delta_2 \) are the increments of cluster head Association and cluster member node Association respectively. After the Ad Hoc network is divided into several cluster units into different network area units, we assign an increment to cluster head and cluster node respectively, considering the relative energy of nodes and the correlation degree of relative distance. This incremental calculation method is given to give cluster head election advantages to cluster heads or cluster members with larger relative energy value or relative node degree in the partitioned area.
3.3. Algorithmic Description and Analysis

Based on the traditional WCA algorithm, TCWCA algorithm considers the incremental factor of topological Association of cluster head node and cluster member node respectively. This makes the choice of cluster head more reasonable and the stability of network topology higher.

The definition of network topology increment proposed in this paper is as follows:

If the node $n$ is selected as cluster head in the last election, then the weight of node $n$ is added with an increment of $\alpha_n \Delta_1$, which is called cluster head topological Association increment. Conversely, if node $n$ is a cluster node, an additional increment of $\beta_n \Delta_2$ is added, which is called the increment of cluster member node topological association. $\alpha_n \Delta_1$ and $\beta_n \Delta_2$ indicate that a cluster head or cluster member node is affected by the topological correlation, and the priority increment is considered in the next election of cluster head. The coefficients $\alpha_n$ and $\beta_n$ are used to control the weights of the incremental constants of cluster head and cluster member nodes respectively. Their values are related to the topological correlation coefficient $Q_n$. For the cluster head continuity advantage and the relative performance election of cluster nodes, the base values of $\alpha_n$ and $\beta_n$ are different, which are discrete variables determined in real time for the system based on the calculation results of $Q_n$. The discrete values of coefficients $\alpha_n$ and $\beta_n$ are as follows:

$$
\alpha_n = \begin{cases} 
0, & Q_n < V_{T1} \text{ or node } n \text{ is a normal node} \\
0.39, & V_{T1} < Q_n < V_{T2} \\
0.64, & Q_n > V_{T2}
\end{cases}
$$

$$
\beta_n = \begin{cases} 
0, & Q_n < V_{T3} \text{ or node } n \text{ is cluster head node} \\
0.24, & V_{T3} < Q_n < V_{T4} \\
0.49, & Q_n > V_{T4}
\end{cases}
$$

In the above formula, the calculation formula of $Q_n$ is as follows:

$$
Q_n = k_e \left( \frac{E_n - \bar{E}}{\bar{E}} \right) + k_d \left( \frac{D_n - \bar{D}}{\bar{D}} \right)
$$

In the above formula, $\bar{E}$ and $\bar{D}$ are the mean energy and the mean node degree of all nodes in the intersection area of a specific topological region and the coverage of nodes. The larger the ratio of the energy difference between node $n$ and the mean energy in the partitioned region $\frac{E_n - \bar{E}}{\bar{E}}$ indicates that the larger the relative energy value of node $n$ in the partitioned topological region is, the more suitable it is to serve as cluster head. The larger the difference ratio $\frac{D_n - \bar{D}}{\bar{D}}$ between node degree of node $n$ and average node degree of partition area is, the larger the relative node degree of node degree of node $n$ is, the more suitable it is for cluster head. In addition, according to the different state information of nodes in the network, the relative energy value and the relative node degree can be adjusted by controlling the values of parameters $k_e$ and $k_d$, which satisfies: $k_e + k_d = 1$.

The detailed description processes of TCWCA algorithm are as follows:

Step1 In the initialization stage, the nodes in the network are in the undetermined state. Through periodic interaction information, each network node obtains the information of other nodes in its coverage. The degree $d_n$ of each node $n$ and its degree factor $D_n$ are calculated.

Step2 The distance factor between nodes $S_n$ and mobility factor $M_n$ of node $n$ are calculated.

Step3 The network energy factor $E_n$ of node $n$ is calculated, and the relative area is divided according to the determined network topology. The ratio of energy difference $\frac{E_n - \bar{E}}{\bar{E}}$ and the ratio of node degree difference $\frac{D_n - \bar{D}}{\bar{D}}$ are calculated. Then the comprehensive factor $Q_n$ of topological correlation is calculated.

Step4 The discrete values of the topological correlation coefficients $\alpha_n$ and $\beta_n$ are determined. The increments of topological correlation of cluster head and cluster member nodes are calculated, which are $\alpha_n \Delta_1$, $\beta_n \Delta_2$. 
Step5 For the same network topology state, the values of parameters $a, b, c, d, k$ are fixed, and the sum of $a, b, c, d$ is 1. $(1 - k(\alpha_n + \beta_n))$ is a feedback regulator, which acts on the distance factor between nodes $S_n$ and the energy factor of nodes $E_n$.

Step6 If the weight of node $n$ is less than that of all neighbor nodes, the node will automatically become the cluster head node and send cluster head messages to its neighbor nodes. If the neighbor node weight of node $n$ is greater than that of node $n$, node $n$ will send a join request message to the nearest cluster head node and become a member node of the cluster head node.

Step7 When the node $n$ becomes a cluster head node, it sends cluster head messages to its neighbors; if the node $n$ becomes a cluster member node, it modifies the cluster member flag bit in the interactive message and indicates the information of the cluster head node to which it belongs; If node $n$ is neither a cluster head node nor a cluster member node, it will be clustered separately.

Step8 TCWCA algorithm stipulates that if the weight of cluster head is equal in the process of election, the node with larger topological Association factor $Q_n$ is chosen as cluster head node.

Step9 Cycle Step1 to Step8 until all nodes join the cluster structure.

4. Simulation Verification

4.1. Simulation Performance Index

In order to verify the performance of this algorithm, the network performance of the minimum ID algorithm, WCA clustering algorithm and TCWCA clustering algorithm proposed in this paper are compared and analyzed through the network level simulation platform. In the simulation scenario, the number of nodes is set to 50-300 in a square area of 1000m *1000m. The transmission range of each node is 100-300 m, and the moving speed of the node is set to 0-20 m/s. The Random Waypoint model is used as the node moving model. The total simulation time is 300 seconds and the node broadcast period is 5 seconds.

In TCWCA algorithm, the parameters are set as follows: $a = 0.65$; $b = 0.15$; $c = 0.1$; $d = 0.1$; $k = 1.2$. Maintain the same weight ratio of the same factor in WCA algorithm. In addition, the incremental constant of topological correlation $\Delta_1 = 1$ and $\Delta_2 = 0.7$ are set. The coefficient $k_e = k_d = 0.5$, and the threshold value of the comprehensive relative factor $Q_n$ is set as follows: $V_{T1} = V_{T3} = 0.01; V_{T2} = V_{T4} = 0.2$.

The simulation variables selected in this paper include the number of network nodes, the moving speed of nodes, the transmission range of nodes, and the distance radius of the partition of the topological region involved in the proposed algorithm. The simulation variables include the number of cluster head nodes and the change rate of cluster head. 100 simulations were carried out to calculate the average of the above network performance indicators.

4.2. Analysis of Simulation Results

Firstly, in the network using the minimum ID algorithm, the traditional WCA algorithm and the TCWCA algorithm proposed in this paper, we simulate and analyze the change of cluster head node number with the number of network nodes. Set the moving speed of nodes to be 10m/s, the transmission range of nodes to be 200m, and the partition distance of TCWCA algorithm to be 180m.

As is shown in Figure 5, the number of cluster head nodes increases with the number of network nodes, but the number of cluster heads formed by TCWCA algorithm is the least under the same conditions. This is because the TCWCA algorithm takes into account the degree of nodes, the distance between nodes, the mobility of nodes, the energy factor of nodes, and the stability factors of the topological correlation.
When the number of nodes is 50, the transmission range of nodes is 200 m, and the partition distance of the topological area in TCWCA algorithm is 180 m, the change rate of cluster head in the network varies with the moving speed of nodes as shown in Figure 6. With the increase of node moving speed, the change rate of network cluster head shows an increasing trend, which means that the change of node moving speed will affect the topological stability. Comparatively speaking, WCA and TCWCA take into account the mobility of nodes, so the stability of network cluster structure is better than that of the minimum ID algorithm. In addition, the TCWCA algorithm takes into account the change and correlation of the topology around the nodes, so the cluster structure formed is more stable and the change rate of cluster head is lower.

As is shown in Figure 7, with the increase of the transmission range of nodes, the cluster head change rate corresponding to the three algorithms all peaked at 150 m, and the cluster head change rate
of WCA algorithm and TCWCA algorithm is significantly less than that of minimum ID algorithm. At the peak, the cluster head change rate of TCWCA algorithm is the lowest, which shows that the clustering stability of this algorithm is the best.

5. Conclusion

In this paper, the principle of weighted clustering algorithm for Ad Hoc networks and the shortcomings of existing technologies are analyzed. An improved network weighted clustering TCWCA algorithm based on topological correlation is proposed. This algorithm not only considers the node degree, the distance between nodes, the mobility of nodes and the energy factor of nodes, but also introduces the increment of topological association between cluster head nodes and cluster member nodes. Compared with the traditional WCA algorithm, the TCWCA algorithm proposed in this paper takes better account of the impact of network topological correlation on cluster head election process. The performance analysis experiments and simulation results show that under the same conditions, the TCWCA algorithm proposed in this paper can reduce the number of cluster head nodes and the change rate of cluster head in the process of cluster head election, and the cluster structure formed has higher stability.

References

[1] Bixiao X U, Jingjing X U, Zhang X, et al. WSN location algorithm based on connective information and heuristic decision on route[J]. Journal of Nanjing University of Posts & Telecommunications, 2016.

[2] Chatterjee M, Das S K, Turgut D. WCA: A Weighted Clustering Algorithm for Mobile Ad Hoc Networks[J]. Cluster Computing, 2002, 5(2):193-204.

[3] Choi W, Woo M. A Distributed Weighted Clustering Algorithm for Mobile Ad Hoc Networks[M]. 2006.

[4] Sharma A, Kansal P. Energy efficient load-balanced clustering algorithm for Wireless Sensor Network[C]// India Conference. 2016.

[5] Ouchitachen H, Hair A, Idrissi N. Improved multi-objective weighted clustering algorithm in Wireless Sensor Network[J]. Egyptian Informatics Journal, 2016, 18(1):S1110866516300160.

[6] TANG Tao, LIU Gaixia, ZHONG Wenjuan, et al. A multi-parameter weighted clustering algorithm for mobile ad hoc networks [J]. journal of chongqing university, 2014, 37(2):106-112.

[7] Chang L, Wang Y, Fan H, et al. A novel enhanced weighted clustering algorithm for mobile networks[C]// International Conference on Wireless Communications. 2009.

[8] Yu-Qing M A , Xiao-Yu L I . Adaptive security weighted clustering algorithm of Ad Hoc network[J]. Computer Engineering and Design, 2014.

[9] SHAN Qi, JIA Shi-lou, et al. On-demand Weighted Clustering Algorithm for Ad hoc Network and Ist Perforrnance Analysis [J]. Journal of Nanjing University of Technology (Natural Science Edition), 2006, 30(5):599-602.