Clustering algorithm based on analytic hierarchy process in LTE-V2V

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Abstract. As a hot area of urban transportation, the development of internet of vehicles and related technologies has received widespread attention. This paper proposes an analytic hierarchy process clustering algorithm (AHP-CA) based on the analytic hierarchy process in the LTE vehicle self-organizing network in the scenario of urban two-direction road intersections. The AHP-CA algorithm introduces the average distance between vehicles, normalizes the average relative speed, and uses the average relative motion direction as the vehicle eigenvalue for the clustering index. The analytic hierarchy process (Analytic Hierarchy Process, AHP) is used to determine the weights of different vehicle feature values, and the appropriate nodes are selected as cluster heads by combining the weights. The simulation results verify the stability of the cluster head under different vehicle speeds and communication distances.

1. Introduction

In recent years, with the advancement of society and science and technology, the automobile industry has flourished. The advancement of communication technology has made communication between cars a reality. However, problems followed, including road congestion, frequent accidents, and low efficiency of urban road networks. Therefore, research on Intelligent Traffic Systems (ITS), Vehicular Ad Hoc Networks (VANETs) and related technologies has attracted great attention from researchers and institutions at home and abroad [1]. As an important part of the intelligent transportation network, vehicle-to-vehicle communication is based on intelligent transportation systems and sensor network technologies. Vehicles are equipped with wireless communication devices for vehicle-to-vehicle (V2V), vehicle-to-vehicle, and basic Facility communication (Vehicle to Infrastructure, V2I) and vehicle to pedestrian (V2P) communication, truly achieve the interconnection of vehicles and everything, organically integrate transportation and surrounding road environment.

Compared with the wireless network based on the IEEE 802.11p protocol, by combining the faster and more stable LTE and V2V technology, this is a technological innovation for vehicle network communication. LTE-V2V will have greater market prospects and higher and more stable performance guarantees, which will also be the general trend of future IoV communication.
2. Traffic scene model and problem analysis

The V2V communication scenario is based on two communication methods, one is based on the PC-5 interface, and the other is based on the Uu interface. LTE-V-Direct relies on the PC5 interface, and LTE-V-Cell relies on the Uu interface, as shown in Figure 1. The communication method based on the PC-5 interface does not go through the transfer of E-UTRAN, it directly sends messages between vehicles, and the transmitting vehicle sends the information to the receiving vehicle. In the communication mode based on the Uu interface, the transmitting vehicle sends a message to the E-UTRAN through the uplink, and then the E-UTRAN sends the message to the receiving vehicle through the downlink. Therefore, when we research short-distance communication transmission, the method based on the PC-5 interface is generally used, and when we research long-distance V2V communication transmission, the method based on the Uu interface is usually used. The application scenario of the algorithm proposed in this paper uses a communication method based on the PC-5 interface [2].

3. Analytic hierarchy process clustering algorithm (AHP-CA)

The scenario proposed in this article is a scenario where vehicle nodes are driving on a two-lane road surface, as shown in Figure 2. The following assumptions are made for this scenario model:

- 1. LTE base station (evolved node B, eNodeB) is deployed on the side of the road to cover this section of the road.
- 2. Vehicle nodes have a GPS global positioning system, which ensures that vehicle nodes can know their position information, speed direction, etc. at any time.
- 3. All vehicles in the access network have the same transmit power and can receive messages across the entire frequency band.

There are many clusters in the connected vehicle network in this scenario. The nodes in the same elliptical virtual circle represent the same cluster. The vehicles marked in red in each cluster are the cluster head vehicle nodes of the cluster. There are multiple cluster nodes in each cluster. Member vehicle nodes and a cluster head vehicle node. Only vehicles with similar mobility can be assigned to the same cluster [3]. Only the cluster head node is responsible for interacting with the eNodeB to obtain communication resources, and it is also responsible for resource allocation within the cluster. The eNodeB no longer participates in intra-cluster communication after allocating resources to the cluster head in the form of resource blocks.

3.1 Analytic hierarchy process

Analytic Hierarchy Process (AHP) is a decision analysis method that combines qualitative and quantitative methods to solve complex problems with multiple objectives. Reasonably give the
weights of each standard for each decision-making scheme, use the weights to find the order of the pros and cons, and apply them more effectively to problems that are difficult to solve with quantitative methods [4]. The basic idea of the analytic hierarchy process is to hierarchically analyze the problems, which are mainly divided into: the target layer, the criterion layer, and the solution layer. For the traffic scenario set in this article, the target layer is selecting the cluster head from which the nodes in the cluster, the criterion layer is composed of average distance between vehicles, the normalized average relative speed, and the average relative direction of movement; the solution layer is the all vehicle nodes. As shown in Figure 3.

![Figure 3. Model hierarchy diagram](image)

The method of constructing the judgment matrix in the analytic hierarchy process is the consistent matrix method, instead of comparing all the factors together, they are compared with each other. Relative scales are used for comparison to minimize the difficulty of comparing different factors with each other to improve accuracy [5].

The weight vector is obtained from the comparison matrix established by the criterion layer to the target layer, and then the weight vector of each scheme of the scheme layer to each element of the criterion layer is obtained. Based on these two weight vectors, the combined weight of each scheme for the target is obtained, and the combined weight vector result set of the scheme layer to the target layer is obtained. The maximum value in the combination weight vector is the vehicle node selected as the cluster head [6].

### 3.2 Clustering indicator parameters

The traffic scene is defined on a two-dimensional coordinate axis, and the coordinates of each vehicle in the scene at time t are (x, y). Then the distance between vehicle i and vehicle j at time t is

$$d_{ij}(t) = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}$$  \hspace{1cm} (1)

Then the average distance between vehicles at vehicle node i at time t is

$$D_i(t) = \frac{1}{n_i} \sum_{j=1}^{n_i} d_{ij}(t), \forall j \in n_i$$  \hspace{1cm} (2)

$n_i$ is the number of neighbor nodes of vehicle node i, and j is the neighbor node of vehicle node i. We also need to consider the relative speed between vehicles. The normalized relative speed between vehicle i and vehicle j at time t is

$$v_{ij}(t) = \frac{|v_i - v_j|}{|v_i| + |v_j|}$$  \hspace{1cm} (3)

Then the normalized average relative speed of vehicle node i at time t is

$$V_i(t) = \frac{1}{n_i} \sum_{j=1}^{n_i} v_{ij}(t), \forall j \in n_i$$  \hspace{1cm} (4)

Finally, we need to consider the relative movement direction between vehicles. The angle between the relative movement direction of vehicle i and vehicle j at time t is

$$\alpha_{ij}(t) = \arccos \left( \frac{\nu_{ij}(t)\nu_{ij}(t) + v_{ij}(t)\nu_{ij}(t) + v_{ij}(t)}{\sqrt{\nu_{ij}(t)^2 + v_{ij}(t)^2 + v_{ij}(t)^2}} \right)$$  \hspace{1cm} (5)

Then the average relative motion direction of vehicle node i at time t is

$$\theta_i(t) = \frac{1}{n_i} \sum_{j=1}^{n_i} \alpha_{ij}(t), \forall j \in n_i$$  \hspace{1cm} (6)
4. Simulation results and results analysis

The algorithm proposed in this paper is implemented using SUMO, NS-3 and MATLAB platforms [7]. Use SUMO to build traffic scenes and generate motion trajectories and parameters. The NS-3 platform is used to manage the node entity classes. Finally, MATLAB is used to generate the corresponding simulation results. The simulation parameters are shown in Table 1.

| Simulation parameter name          | Values         |
|------------------------------------|----------------|
| Road length                        | 1000m          |
| One hop transmission distance      | 20-100m        |
| Number of nodes                    | 100            |
| Minimum speed                      | 20km/h         |
| Maximum speed                      | 50km/h         |

**Figure 4.** One hop communication distance and cluster head duration

**Figure 5.** Vehicle speed and cluster head duration

From Figure 4 and Figure 5, it can be concluded that as the one-hop communication distance of a node gradually increases, the number of neighbor nodes within the range of the node will increase accordingly, and the selection range of the cluster head node will also increase. The clustering algorithm based on the Lowest ID will update the cluster head node fixedly within a certain period of time, but with the communication distance increases, the cluster head node will be more easily replaced by other nodes, so that the cluster head has a duration reduce. The clustering algorithm based on the analytic hierarchy process proposed in this paper can maintain a relatively stable cluster head when the communication distance increases. In addition, as the vehicle's driving speed increases, road
conditions change rapidly, and the information of each node is updated quickly, which will cause clustering instability and frequent replacement of cluster heads. As can be seen from the figure, the clustering algorithm designed in this paper is still superior to the traditional Lowest ID-based clustering algorithm in terms of cluster head stability.

5. Conclusion
This paper proposes a clustering algorithm based on analytic hierarchy process in LTE vehicle self-organizing network. The AHP-CA algorithm introduces the average distance between vehicles, normalizes the average relative speed, and the average relative motion direction as the vehicle eigenvalue for the clustering index. The analytic hierarchy process is used to establish the contrast matrix, obtain the combined eigenvector values, and determine the cluster head nodes. Compared with the classical algorithm, this algorithm has a greater ability to maintain the stability of the cluster head when the communication distance increases and the vehicle speed increases.

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