A Design of D2D-Clustering Algorithm for Group D2D Communication

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Abstract. Due to the characteristics of low latency and proximity discovery, D2D communication is considered to have an inherent advantage in supporting Internet-of-Vehicles (IoV) service. In this paper, considering that vehicular users can detect neighbor nodes in adjacent areas which are able to maintain high reliable communication with themselves, a novel design of D2D-Clustering algorithm is proposed in order to improve the QoS of users. The algorithm uses undirected graph to describe the neighborhood relationship between users. And the undirected graph is continuously simplified by multi-round traversal of vehicular users until user clustering is completed. Simulation results prove the validity of the proposed algorithm, pointing out that it helps reduce the energy consumption of the whole system.

Keywords: Internet-of-Vehicles · D2D communication · Clustering · Neighbor detection · Undirected graph

1 Introduction

Intelligent Transportation System (ITS) provides support for various kinds of applications for IoV, making modern transportation much more efficient [1]. However, with the massive access of intelligent devices, mobile communication traffic is increasing rapidly, which brings huge burden to cellular network. 3GPP proposed Device-to-Device (D2D) communication technology in LTE Release 12. Due to the way of short-distance direct communication, D2D Technology has less energy consumption and lower transmission latency, solving the contradiction between throughput and reliability in traditional cellular network. It has been considered as a promising candidate technology to support vehicle-to-everything (V2X) services. D2D based V2X enables vehicles to quickly exchange information with adjacent vehicles, pedestrians, road-side units [2], etc. It is an excellent solution to improve the quality of service for IoV users.

In many scenarios, base stations need to continuously broadcast the same or similar content due to the common interests from a large number of users, such as a crowded concert or stadium. These services generate a rather steady load at the physical layer. In other words, base stations will need to send small-scale

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data packets to most of the users in the cell periodically. The same is true for many V2X services, such as road condition update service and traffic accident broadcasting. Beacons which are used to mark specific events need to be periodically transmitted in a reliable way [3]. Thus, it is very important to design a good multicast scheme for this kind of service. In [4], the author put forward the concept of D2D multicast communication. Through D2D multicast communication, user can share information data to its multiple neighbors using the proximity relationship of user equipment's location. Therefore, the introduction of D2D multicast technology helps expand the coverage of multicast services and share common content between users, reducing the load of base stations.

For the scenarios with periodic transmission opportunities at the physical layer, a persistent resource scheduling scheme LDRAS is proposed in [3]. LDRAS divided each cell sector into several spatially disjoint regions, where in which region a fixed but different set of RBs is preserved for D2D users and cellular users (C-UE). The resource scheduling is mainly dependent on the current location of users. Besides, in order to limit the interference of D2D transmission to conventional cellular users, C-UE region must be far enough separated from D2D region when they share the same set of RBs.

Considering that mobile devices with interest in the same content in the network can be grouped into a cluster under the existing system framework, the introduction of D2D clustering is a great promotion to improve system performance. In [5], Peng et al. proposed a cooperative communication scheme, in which base station and D2D transmitters were in charge of two-round broadcasting, respectively. Thus, the QoS of mobile video service of cell-edge users can be improved. The researches in [4] and [6] focused on how to determine whether user devices should work under D2D multicast communication mode or cellular communication mode, and the mode switching conditions. In [7], Koskela et al. derived the mathematical solution equation for assigning optimal communication mode for devices by introducing the concept of clustering with mode switching. It was pointed out that the system performance in the optimal communication mode is related to degree of separation of cluster members. On the other hand, the researches in [8] and [9] focused on D2D user clustering algorithm. A D2D multicast cluster head selection strategy was presented in [8], which can improve the system throughput and reduce the transmission delay. In [9], Zhu et al. proposed a multicast clustering algorithm for multi-hop communication by introducing cluster head node selection criteria and cluster member reassignment mechanism, efficient intra-group content sharing is achieved and transmission latency is reduced. In [10], a heuristic framework for clustering LTE-D2D devices for group D2D communication was presented. The channel states between users and the residual energy of nodes were mainly considered. However, cluster member assigning mechanism was rather complex.

Many features have been taken into consideration in those researches above, such as multi-hop, multi-mode, buffer-aided and multi-round-cooperation. However, there are still few user clustering schemes serving for efficient D2D multicast communication. Moreover, these existing clustering schemes in related researches do not make full use of the neighborhood relationship between cell users. The principle of opportunism is not followed in the selection of cluster heads. Inspired by the above issues, a novel Undirected Graph Simplification based Clustering (UGSC) algorithm for group D2D communication is proposed in this paper. Channel condition between users is considered as the most critical factor for clustering. After neighbor discovery, user equipments (UEs) update the list of its strong neighbor nodes (SNN) to the evolved Node B (eNB), which controls the D2D clustering. The proposed algorithm creatively uses an undirected graph to describe the neighborhood relationship between user devices in a cell. The undirected graph is continuously simplified in an iterative manner. Finally, D2D clustering of all user devices is completed to serve the subsequent D2D multicast communication.

The rest of this paper is organized as follows. In Sect. 2, the scenario description and neighbor detection mechanism are given. In Sect. 3, we present the basic principles and procedures of the UGSC algorithm. Simulation results and analysis are provided in Sect. 4. Finally, conclusions are drawn in Sect. 5.

2 System Model

2.1 Scenario Description

We consider a single-cell scenario as shown in Fig. 1, where there are M vehicular-user equipments (V-UEs) running V2V applications. Each V-UE is equipped with one antenna. U_i denotes the i^{th} V-UE. h_{ij} represents the channel coefficient between U_i and U_j. Besides, We use P_B and P_u to denote the transmitting power of eNB and V-UEs respectively. So, the Signal-Interference-Noise-Ratio (SINR) for the transmission between U_i and U_j is calculated as:

$$\gamma_{ij} = \frac{P_u |h_{ij}|^2}{\sigma_n^2}, \ \forall i, j \in \{1, 2, \ldots M\} \tag{1}$$

Where σ_n^2 is the variance of the channel noise.

2.2 Detection of Strong Neighbor Nodes

Each UE can execute neighbor node discovery algorithm to finding out other UEs near itself [11]. Specifically speaking, U_i performs channel estimation based on the discovery beacon (reference signal) sent by the surrounding nodes and calculate the SINR of the reference signal. If the SINR is higher than a given threshold, the UE which sent that beacon will be considered as a strong neighbor node to U_i. Then U_i will add it to its own list of strong neighbors $\mathbf{SNN}_i$ and reply with an acknowledgment beacon.

After the strong neighbor node detection process is finished, the neighbor lists will be reported to eNB using the granted Physical Uplink Shared Channel (PUSCH) [12,13]. One RB is always preserved for updating the table of Strong-Neighbor-Node $\mathbf{SNN}_i$. Clearly, eNB can also obtain the channel state information of all UEs at the same time, which is preserved as $\mathbf{TAB}_{SINR}$. Under the

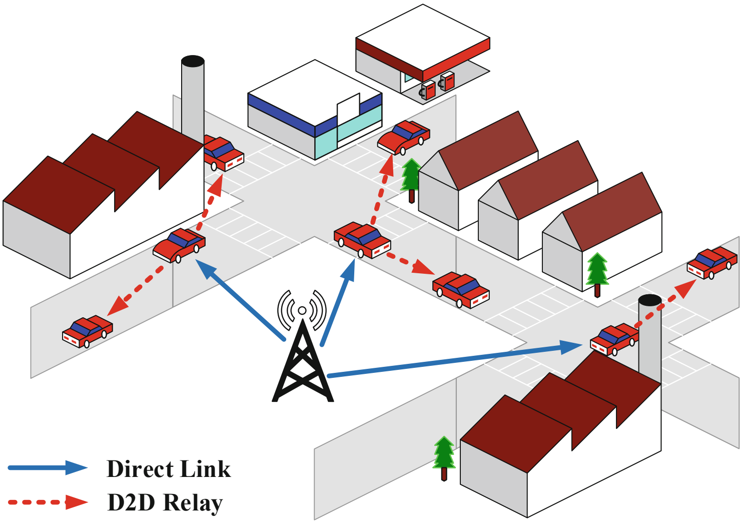

Fig. 1. Urban vehicular network scenario

assumption of channel reciprocity, the eNB will consider two V-UEs as strong neighbors if they are in each other's neighborhood list. Note that, such an updating process does not need to be performed very frequently in order to reduce signaling overhead in the system. The eNB can perform information uploading over large time scale cycles (e.g., hundreds of milliseconds) according to specific V2V application service types.

3 UGSC Algorithm

Clustering and the following resource scheduling is controlled by eNB. Firstly, a few cluster heads (CHs) and their corresponding cluster members are selected by eNB according to **SNN** and $\mathbf{TAB}_{SINR}$. Then, the eNB allocates time-frequency resources to each cluster for the subsequent information exchange inside each cluster. The key point of this paper is to design a reasonable and fast D2D-Clustering algorithm, reducing the complexity of the algorithm and the energy consumption of whole system.

Consider the neighborhood relationship between V-UEs in a cell as an undirected graph. Clearly, each vertex represents a V-UE. The edge between two vertices represents that the corresponding V-UEs are strong neighbor to each other. The key idea of the UGSC Algorithm is to simplify the undirected graph in multi-round iterations according to the distribution of edges between different vertices. Here are the basic principles and procedures of the UGSC Algorithm.

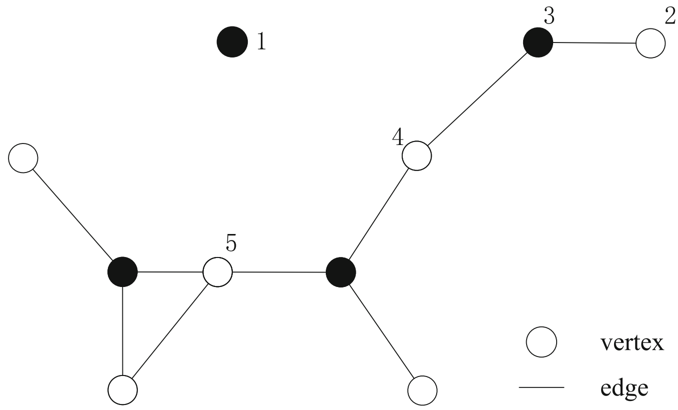

Fig. 2. A possible state in clustering process

3.1 Basic Principles

- If there is no edge connected to one specific node (like Node **No. 1** in Fig. 2), this node will be labeled as an isolated vertex. It means that there is no proximity between this V-UE and other V-UEs in the cell. The eNB must regard this kind of node as an individual cluster, the CH of which is the node itself. The eNB will communicate with it directly.
- If there is only one edge connected to one specific node (like Node **No. 2** in Fig. 2), this node will be considered as a terminal vertex. It means that there exists only one strong neighbor node (like **Node No. 3** in Fig. 2) to this V-UE. In this situation, the eNB must regard the connected neighbor node as a CH, while this terminal node becomes a member of the cluster. The eNB will communicate with this terminal node at the assistance of the corresponding CH.
- If there are more than one edges connected to one specific node (like **Node No. 4** and **No. 5** in Fig. 2), this node will be considered as a multi-joined vertex. The eNB can not determine that whether this node should be regarded as a CH node or an ordinary cluster member immediately. In this situation, we should firstly turn to its strong neighbor nodes, checking that whether anyone of them has been regarded as a CH or not.

In other words, due to the existence of multi-joined vertices, it is not enough to complete the whole clustering process through only one-round traversal of all V-UEs in the cell. Thus, we propose an iterative algorithm for cyclic traversal. In each round of iteration, V-UEs that were assigned to a specific cluster will be removed from the list. By doing so, irrelevant vertices and edges in complex undirected graph are gradually deleted until the assignment of all V-UEs is finished.

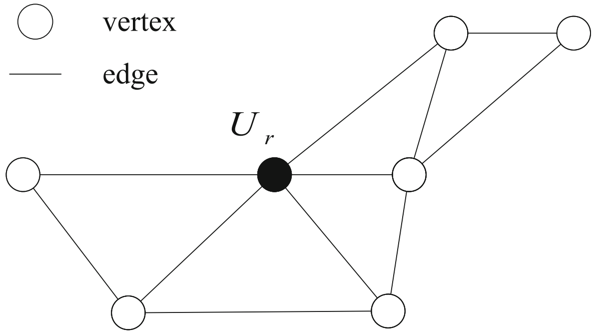

Fig. 3. The Impasse-Break mechanism

3.2 Procedure

The procedure of UGSC Algorithm is shown in Algorithm 1.

As shown in Step 2–6 in Algorithm 1, in each round of traversal, we find out the set of all unreachable nodes $\mathbf{K}_0$ from the set of unassigned nodes $\mathbf{K}$ firstly. Clearly, each node in $\mathbf{K}_0$ will be assigned to an individual cluster by the eNB. After this step of assignment, those mentioned nodes must be deleted from **K** and **SNN**.

Then, as shown in Step 7–15 in Algorithm 1, we find out the set of all single-connection nodes $\mathbf{K}_1$ from **K**. The single strong neighbor node of these nodes in $\mathbf{K}_1$ will be assigned as CHs, while nodes in $\mathbf{K}_1$ become members of corresponding clusters. Note that, the neighbor list of the aforementioned selected CH may contain more strong neighbor nodes except that single-connection one. For example, **Node No. 2** in Fig. 2 is a single-connection node. If we assign **Node No. 3** as a CH, we have to pay attention that the neighbor list of **Node No. 3** contains not only **Node No. 2** but also other nodes. These nodes may already be assigned as a cluster member or may be in an uncertain state. At this time, we should add nodes in uncertain state to a pending-node set **PN**. Once the traversal of $\mathbf{K}_1$ is finished, we should start the traversal of **PN**, in which we find the most suitable (the best channel condition) CH for each node in **PN** and make them a cluster member of their most suitable CH. Similarly, after this step of assignment, those mentioned nodes which have been assigned as a cluster member must be deleted from **K** and **SNN**. The process is repeated until **K** becomes an empty set, meaning that assignment of all V-UEs is finished.

It is worthy to mention that the continuous deletion of UE in the table of Strong Neighbor Node **SNN** and set of unassigned nodes **K**, is exactly the process of continuous simplification of the complex undirected graph corresponding to cell network. The whole process may turn into a special state, which is like what can be seen in Fig. 3. In this situation, **K** is not an empty set. However, there is no unreachable node or single-connection node in **K**. We propose an Impasse-Break mechanism that an unassigned node U_r is randomly selected as the CH of a new cluster. All of the strong neighbor nodes of U_r are assigned

Algorithm 1. Proposed UGSC Algorithm

Input: The Set of Unassigned Nodes, $\mathbf{K}$; The Table of Strong Neighbor Nodes, $\mathbf{SNN}$; The Table of CSI of All Nodes, $\mathbf{TAB}_{SINR}$;
Output: The Set of Cluster Members, $\mathbf{C}$; The Set of Cluster Heads, $\mathbf{CH}$;
1: **while** $\mathbf{K} \neq \emptyset$ **do**
2: Find all unreachable nodes in $\mathbf{K}$ as set $\mathbf{K}_0$;
3: **for** each $U_i \in \mathbf{K}_0$ **do**
4: Update $\mathbf{C}, \mathbf{CH}, \mathbf{K}$ with U_i; //New cluster consists of U_i
5: **end for**
6: Update $\mathbf{SNN}$ with existing $\mathbf{K}$;
7: Find all single-connection nodes in $\mathbf{K}$ as set $\mathbf{K}_1$;
8: **for** each $U_i \in \mathbf{K}_1$ **do**
9: Update $\mathbf{C}, \mathbf{CH}, \mathbf{K}$ with U_i ans SNN_i; //New cluster consists of U_i and SNN_i.
10: $\mathbf{PN} = \mathbf{PN} \cap \mathbf{SNN}_{SNN_i}$; //Gather all neighbor nodes of SNN_i
11: **end for**
12: **for** each $V_i \in \mathbf{PN}$ **do**
13: Update $\mathbf{C}, \mathbf{K}$ with V_i; //join in the best CH
14: **end for**
15: Update $\mathbf{SNN}$ with existing $\mathbf{K}$;
16: **if** $\mathbf{K}_0 = \emptyset$ and $\mathbf{K}_1 = \emptyset$ **then**
17: Randomly select $U_r \in \mathbf{K}$ as a new CH, remove U_r from $\mathbf{K}$;
18: Update $\mathbf{C}, \mathbf{CH}, \mathbf{K}$ with U_r;
19: Update $\mathbf{SNN}$ with existing $\mathbf{K}$;
20: **end if**
21: **end while**
22: **for** each ordinary cluster member U_i **do**
23: Update $\mathbf{C}, \mathbf{CH}$ with Reassignment of U_i; //join in the best CH
24: **end for**
25: **return** $\mathbf{C}, \mathbf{CH}$;

as the ordinary members of the cluster. Similarly, after this step of assignment, those mentioned nodes must be deleted from **K** and **SNN**. Then, we start a new round of traversal. In the scenario where multiple UEs are adjacent to each other but separated from the majority of other cell users, the proposed Impasse-Break mechanism effectively avoids the clustering algorithm entering a dead-cycle state. The Impasse-Break mechanism is shown in Step 16–20 in Algorithm 1.

Finally, due to the Impasse-Break mechanism, new CH is randomly selected by eNB. So, it is possible that some V-UEs are not with their optimal choice of CH (there may exist CH with better channel condition) when assignment of all V-UEs is finished. In this situation, a reassignment step is needed. We check every ordinary cluster member whether its CH is the optimal choice of CH (the best channel condition). If it isn't, then this node joins in the cluster corresponding to its optimal choice of CH. Reassignment Mechanism is shown in Step 22–24 in Algorithm 1.

4 Simulation Results

In this section, we provide Monte-Carlo simulations to evaluate the performance of the proposed algorithm.

4.1 Road Configuration and Channel Model

At first, road configuration for simulation is shown in Fig. 4. We set two Manhattan grids so the size of simulation area is 433 m × 500 m. There are 2 lanes in each direction of every street. For V-UE drop modeling, we assume all V-UEs in the same lane have the same speed. The distance between two V-UEs in the same lane obeys exponential distribution, while the average inter-vehicle distance is 2 sec × the speed of V-UE [14].

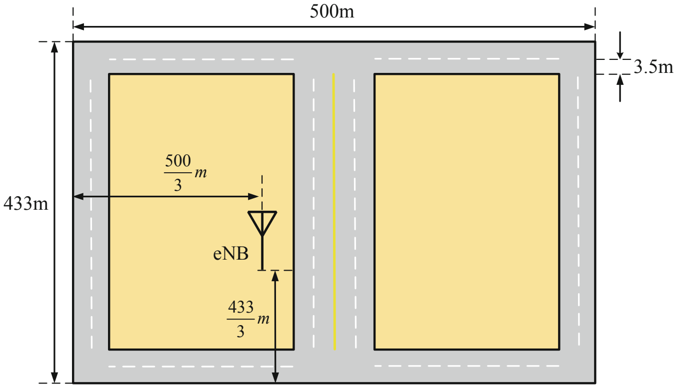

Fig. 4. Road configuration for simulation

Then, we use the channel model of V2V link for the urban grid scenario from [15]. Furthermore, we set the shadowing standard deviations as 3 dB and 4 dB for LOS(NLOSv) state and NLOS state. The probability of V2V links being LOS(NLOSv) or NLOS state is determined by transmission distance and whether the path is blocked by buildings or vehicles. The pathloss calculation for LOS and NLOSv link is:

$$PL = 38.77 + 16.7\log_{10}(d) + 18.2\log_{10}(f_c), \quad LOSLink \tag{2}$$

$$PL = 36.85 + 30\log_{10}(d) + 18.9\log_{10}(f_c), \quad NLOSLink \tag{3}$$

Where d denotes the Euclidean distance between transmitter and receiver in meters, while f_c denotes the carrier center frequency.

Simulation parameters are summarized in Table 1.

Table 1. Simulation parameters

Parameter	Value
Carrier center frequency	2 GHz
System bandwidth	10 MHz
Transmitting power of V-UE	23 dBm
Transmitting power of eNB	43–48 dBm [16]
Noise spectral density	−165 dBm/Hz
V-UE SINR threshold	20 dB [17]
Speed of V-UEs	60 km/h
Data packet size	1 KB

4.2 Simulation Setup

Simulation setup for the eNB and V-UEs is given. We assume that the eNB is an LTE base station sending packets with a data rate of 100 Mbps. Its transmitting power is in the range of 43–48 dBm relying on the reference signals received from V-UEs. When there is no clustering, the eNB needs to serve all V-UEs in cell. As for the clustering case, eNB only sends packets to those CHs. In the following, we assume that the CHs will send packets to their ordinary cluster members with a data rate of 1 Mbps and a turbo code rate of 1/3.

4.3 Results and Analysis

For the performance comparison, the D2D-clustering algorithm proposed in [10] is used as a baseline scheme, which is called CCRE-based scheme. So, we compare the following three schemes: the proposed UGSC-based scheme, the baseline CCRE-based scheme and the traditional non-clustering scheme.

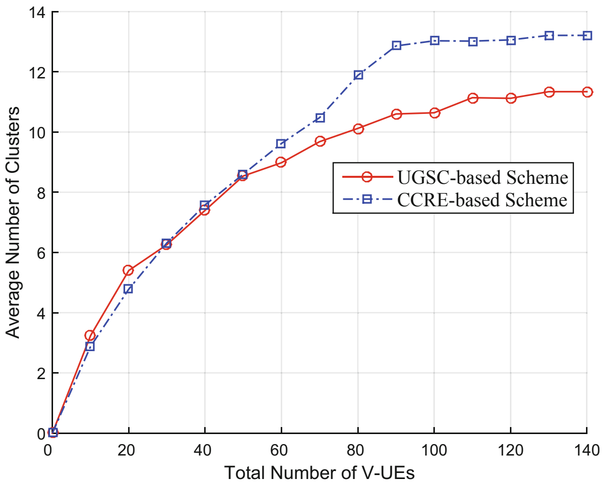

Fig. 5. Average number of clusters vs. number of V-UEs

(1) Validity and Efficiency. As illustrated in Fig. 5, the clustering efficiencies of UGSC-based and CCRE-based schemes are compared as shown in Fig. 5. It can be seen from Fig. 5 that with the increase of the number of V-UEs, the increasing trend of average number of clusters in UGSC-based scheme is similar to that in CCRE-based scheme. In details, the average number of clusters will not increase endlessly, but reach an asymptotic value in both schemes.

Obviously, each V-UE has a greater probability to detect Strong-Neighbor-Nodes around it due to the increasing number of V-UEs. Therefore, they have more opportunities to form a common cluster for efficient content sharing when vehicles are densely distributed, while additional new clusters become unnecessary. Thus, simulation results prove the validity of the UGSC Algorithm. Furthermore, it can be observed that the asymptotic value of number of clusters in UGSC-based scheme is smaller than that in CCRE-based scheme. It means that UGSC-based scheme is more effective than CCRE-based one especially in the case of dense traffic.

(2) Energy Consumption. Figure 6 illustrates the total energy consumption of these three schemes. As can be seen in Fig. 6, the energy consumption increases in all schemes, while with clustering the system can achieve an energy-saving gain. Besides, the performance of UGSC-based scheme is similar to that of CCRE scheme when the number of V-UEs is small. However, with the increase of the number of V-UEs, UGSC-based scheme has less energy consumption.

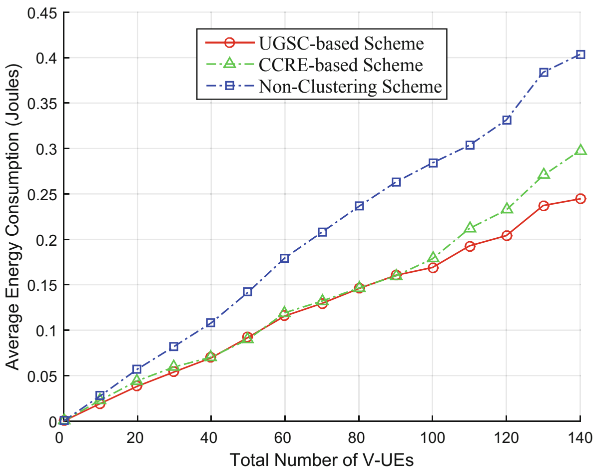

Fig. 6. Average energy consumption vs. number of V-UEs

Furthermore, the gap between energy consumption in three schemes is also gradually widening. Note that, the energy saving of eNB transmission is achieved at the cost of increasing energy consumption of CHs in UGSC-based scheme.

Therefore, with the increasing number of V-UEs, the benefits resulting from clustering become more and more obvious. The energy-saving efficiency is getting higher, respectively. This also proves the validity of the UGSC Algorithm from another point of view.

5 Conclusions

In this paper, we studied the clustering algorithm for group D2D communication in LTE-V2V systems. The Strong-Neighbor-Node detection was carried out on every V-UE in order to provide channel state information of itself to eNB. In the proposed UGSC Algorithm, neighborhood relationship between V-UEs in a cell was considered as an undirected graph. By taking the current unassigned users as the object of traversal, the undirected graph was continuously simplified in an iterative manner. Simulation results proved the validity of the clustering algorithm, pointing out that it is of a promotion on energy saving of the whole system. In the future work, we plan to consider whether to introduce more clustering criteria, including moving state prediction for V-UE, etc.

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