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# *IMCR: Influence Maximisation-based Cluster Routing Algorithm for SDVN*

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***Abstract*—In recent years, with the continuous development of intelligent transportation, vehicular networking has attracted lots of research attention, in particular, for autonomous driving. Vehicular networking can reduce the number of fatalities and injuries in traffic incidents, and bring enjoyment to people. However, as the dynamic vehicular network is designed to transmit reliable massive amount of data reliably, it still faces issues such as overloading, packet dropping and high latency. Therefore, in this paper, we aim to reduce the overheads and improve the efficiency of the transmission by applying the influence maximisation to the dynamic vehicle networks. We propose a double-cluster head routing algorithm for the software-defined vehicular networks (SDVNs), namely, Influence Maximisation-based Cluster Routing algorithm (IMCR), to improve the efficiency and quality of network communication. In the experiments, the results show that compared with the counting algorithms, the proposed algorithm can provide better performance in efficiency, quality and latency of network transmission.**

***Keywords—Software-defined vehicular network, clustering, impact maximisation***

## I. INTRODUCTION

The development of intelligent transportation system (ITS) drives the increase of research and development for autonomous vehicles. With equipping the radar, laser, GPS and other technologies, the unmanned cars can perceive the surrounding situation in real time. However, these sensors still cannot provide communication among vehicles, which is vital to guarantee driving safety. The vehicular networking then brings high cost of network operation and maintenance, which is not acceptable for the commercialisation of autonomous driving [1][2]. Besides, it is expected that more than 10 million self-driving cars will be on the road by 2020 [3]. It can be seen that the continuous expansion of network makes the future vehicular network facing significant challenges, including the process of standardization, which urgently requires us improve the computing capacity of vehicles to the front end, to meet the needs of people's daily life. At present, there have been many studies on the standardization of vehicular network, such as [4]. However, it is not a short-term project. With the development of vehicular network, it needs to be constantly evolved, updated and formulated.

Based on 802.11p [5][6], traditional vehicular ad-hoc network (VANET) is to provide vehicle-to-vehicle and vehicle- to-infrastructure communication. IEEE 802.11p operates at a frequency of 5.9 GHz with seven channels, providing short-distance communication of around 300 m. In recent years, VANET as the main technology of intelligent transportation, has been received extensive concerns by the academic and the industrial with achieved remarkable developments. However, its current architecture is inflexible and inadaptable to meet the specific communication needs of the vehicle network. The deployment and management of network is difficult to achieve when using a fixed routing algorithm to select the message forwarding path. Such architecture is hard to meet the increasing transmission efficiency and the demand for massive data. Thus, it cannot guarantee both the collection and forwarding of data traffic and the reliable transmission of the data messages in the highly dynamic vehicular networks.

In response to the need mentioned above, a new technical architecture software definition network (SDN) [7][8] emerged. SDN provides a new dynamic network architecture, which generally composed of the application program, controller plane and data plane. Compared with the distributed fashioned VANETs, it separates the control plane from the data plane and adopts centralised controller to realise the global view processing through at the controller level. It also realises the architecture based on its core technology OpenFlow, so that it can flexibly control network traffic, effectively solve the problem of high bandwidth, and promote the network virtualisation. Also, the most representative feature of SDN is programmable [9][10], where it gets rid of the limitation of hardware on existing network architectures and better realises network communication. Software-Defined Vehicular Network (SDVN) is the vehicular version of SDN. Compared with VANETs, the routing protocol of the SDVNs supported by SDN solves the above problems to a large extent.

Although SDVN has some unique advantages and can solve some problems that VANET cannot solve, it still has some disadvantages. For communication efficiency, it also faces significant challenges, such as lack of research on routing algorithm in the controller [11], high communication cost [12]. For vehicle networks, routing and forwarding mechanisms have been rarely designed. Although the clustering is a potential solution, it still has severe problems in selecting a cluster head. Although there are many studies on selecting cluster heads in SDVNs, the existing schemes still suffer high packet loss rate, overhead and delay, and low transmission rate. These issues become more apparent when the number of vehicles increases sharply, and networks change rapidly. In addition, similar to VANETs, SDVN is also mobility and fast network

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topology, which requires real-time updates of vehicle status sending to the controller. This leads to the problem of load balancing. Therefore, with facing these challenges, our new routing algorithm is proposed. To address these issues, this paper makes the following contributions.

- To the best of our knowledge, our work is the first one to bring influence maximisation algorithm from social networks to computer networks, in particular for cluster head selection.
- To solve the uplink overhead and delay in network communication, we propose a double-cluster head selection mechanism in clustering. Different from the existing structure of single cluster head, the selection of double cluster head can better solve problems such as packet loss rate especially when the existing cluster head fails.
- By double-cluster head design, we apply the influence maximisation algorithm for the cluster head selection in dynamic vehicle topology network for the first time. Different from the existing selection methods of cluster heads, our proposal selects the heads by considering the degree of mutual influence between vehicles. Hence, the best cluster head can be selected and relevant work can be carried out.

The rest of this article is organised as follows. In Section II, we introduce existing work related to this article. Section III describes the system model. Then Section IV describes some of the work we have done. Then Section V presents our experiment and comparative evaluation of the experiment. Conclusions and future work are summarised in the last section.

## II. RELATED WORK

In this section, we briefly describe the existing clustering and cluster head selection algorithms in SDVNs or vehicular networks.

### A. *Clustering Algorithm*

The rapid development of SDVN requires reliable routing algorithms to support efficient communications. One of the most critical issues in SDVNs is load unbalancing generated from flooding. Clustering is an optimal scheme to reduce latency and improve bandwidth utilisation and network scalability.

Jiaetal. analyses the impact of floating vehicle data (FCD) on other LTE traffic [13], which shows that FCD transmission with cluster head (CH) can improve the network communication efficiency compared with no cluster head. In [14], authors propose a distance-based cluster head selection scheme, providing data aggregation and great load balance for the network. Position and energy measurement-based efficient distributed clustering algorithm [15] reduces the transmission of unnecessary control information in the network, with high efficiency and strong anti-interference ability.

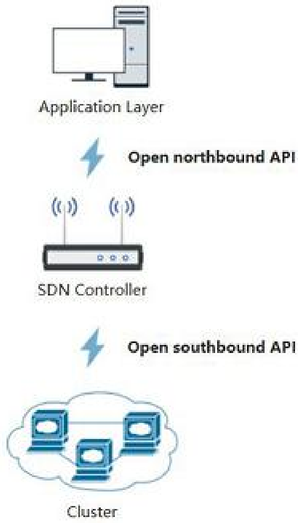

Fig.1. Simplified Software Defined Network architecture

### B. *Cluster Head Selection*

Cluster head (CH) is an indispensable part of clustering schemes. The selected cluster heads collect the relevant state of vehicles and communicate with the base station, which reduces the communication processing delay and uplink overhead. However, different applications have specific functions, and the method of selecting cluster heads is also diverse. A variety of algorithms for selecting cluster heads have been proposed in vehicular communication, but there are still some deficiencies in the existing schemes, such as unbalanced load and failure to fully adapt to the high-density network.

In [16], speed and signal-to-noise ratio (SNR) are adopted to select the cluster head. In this algorithm, the selection of cluster heads depends on the average vehicle velocity and the SNR. The closer the vehicle velocity is to the average cluster velocity, the higher the SNR and the greater the probability of being selected. However, it did not consider the influence of the environment and the dynamic changes of vehicular network topology change. Also, relative speed [17] and link expiration time [18] are also adopted to select cluster head are fast and simple, but this studies cannot fully adapt to the network with high node density. In this case, it may become a victim of the well-known hidden node problem. Lowest-ID algorithm [19] is applied to single-hop cluster for selecting cluster heads based on node id, where nodes with the lowest id will be selected as the cluster heads. This method is also simple and quick, but the main disadvantage is that the load of nodes is not balanced, and the nodes with a small id may lead to the exhaustion of energy. In [20], the Highest-Degree Clustering algorithm also selects the heads regarding the distance. However, the nodes all gather in the cluster, resulting in a sharp increase in throughput.

It can be seen from the above relevant content that both VANETs and SDVNs are still facing challenges in vehicular communication. VANET is a vehicular version of the ad-hoc network, while there are many issues such as unbalanced traffic and inefficient network utilisation in multi-path topology in VANETs.

However, with applying SDN technologys to, SDVN also faces the issues of the reasonable structure design and the lack of reliable routing algorithm. Although the existing cluster algorithm can solve the issue of data traffic forwarding, it also increases the vulnerability of the system. Therefore, in this paper, we adopt a double cluster head structure, which better improves the reliability of vehicular communication and reduces the uplink overhead. Firstly, the design of the standby cluster head is adopted. Secondly, the influence maximisation algorithm is applied to select the proper cluster heads in the dynamic vehicular network.

## III. SYSTEM MODEL

From the perspective of routing, there are mainly three types of SDVNs, including fully-centralised SDVNs, VANET -based SDVNs, and policy-based SDVNs. For fully-centralised SDVNs, all the flow tables (i.e. routes) are computed in the controller once receiving the routing request from the vehicle node [21]. For the VANET-based SDVNs, the networking in the same region still operated ad-hocly, but the controller only assists the nodes for routing. The policy-based SDVNs can be seen as hybrid SDVNs, where the controller only distributes routing policies to the vehicle nodes according to the status of the network [22]. The most distinguished point of SDVNs is, we can adopt the utilisation of its programmable features to allocate resources intelligently, and take the impact of environmental factors into account to better realise vehicular network communication.

### A. Architecture

SDVN is a new type of network architecture providing virtualisation of the network. SDVN applies the core technology of SDN, OpenFlow, to decouple the control plane of network equipment from the data plane, flexible controls the network traffic, and makes the network even more intelligent. Compared to VANETs, SDVNs can provide the prediction of vehicle trajectories, with reducing overhead. An example of SDVN structure is shown in Fig.1. In this paper, we apply the VANET-based SDVNs as our structure. The top layer is the application layer, the layer in the middle is the controller the control logic of the network, and the bottom layer is the router and switch that forwarding the traffic. It introduces programming in the forwarding device through the open southbound interface, and realises the processing of the global view in the controller of the control plane, which ensures the self-adaptation and efficient clustering, and is easy to manage and execute the network. In this paper, we apply the VANET-based SDVNs mentioned above as our structure.

### B. Clustering for SDVNs

Here we expound the design of cluster routing in SDVN. As shown in Fig.2, we divide vehicles into two clusters and select cluster heads in each cluster (V2 and V9) by using clustering algorithm. After partitioning, the cluster head collects vehicle information in the cluster and their dynamic changes, and then sends this dynamic topology to the controller through the

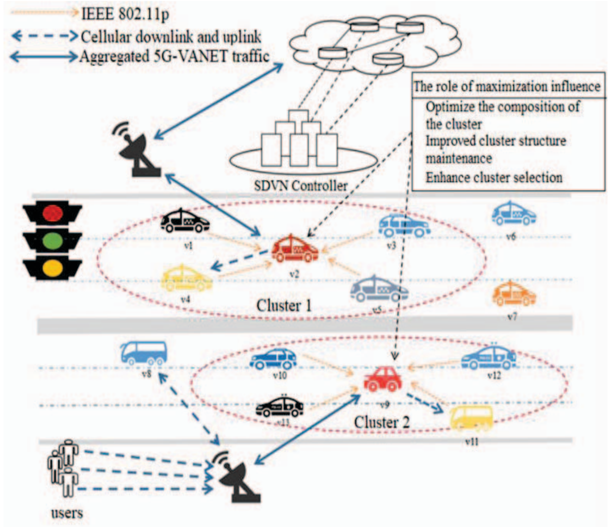


Fig. 2. The structure of Influence Maximisation-based Cluster Routing Algorithm for Software Defined Vehicular Network

aggregated 5G traffic, so that it can instantly grasp the structural topology of the entire network.

## IV. INFLUENCE MAXIMISATION-BASEDCLUSTER ROUTING ALGORITHM FOR SDVN

In this paper, we propose a new routing algorithm for SDVN, namely, *Influence Maximisation-based Cluster Routing Algorithm for SDVN (IMCR)*. One controller is installed for covering a certain range of road segments in order to manage the local data traffic. First, the controller collects the status information of all vehicle nodes, by using a reactive request/reply-fashioned protocol (like AODV). For example, the source vehicle node first communicates with the controller through by using RREQ when it joins a client member of the controller as the first time. Then the controller sends the generated flow table back to the source node for communication.

However, if all vehicle nodes communicate to the controller at the same period, the converging data flow in the uplinks towards the controller will be high. As a consequence, a large amount of uplink overhead can cause further communication delay. To reduce the overhead on the uplink for maintaining the topology information, clustering is an optimal technology where status data are processed and transferred from the vehicles to the cluster head then forwards to the controller.

For clustering, we divide the vehicle nodes into multiple clusters and then select cluster heads in their range. The selected cluster head is responsible for transferring data packets for other cluster members and uploading vehicle information (including vehicle information, location and speed) to the controller. The most important parts of this process are the information maintenance within the cluster, the realisation of unified information uploading function of the cluster, and the uploading and maintenance of status information from the vehicle to the controller. To well present the above three functions, we will introduce our algorithm in two aspects, the application of influence maximisation and the structural design of the double cluster head.

*A. Influence Maximisation for Selecting Cluster Heads*

The influence maximisation algorithm was initially applied in social networks, and many well-known scholars have conducted in-depth studies on it in large-scale networks, such as [23][24]. In this paper, we apply it to the dynamic vehicular network for the first time to obtain the cluster heads and strive for better communication effect.

According to the rule of [25], geographically adjacent nodes will be assigned to the same cluster. Therefore, as shown in Fig.3, we divide the mobile nodes in the network into different virtual groups and then select vehicles as the cluster head in each cluster. A good cluster head should not move quickly, as it can effectively ensure the stability of the mini-network, i.e. its in-charged cluster. This pape applies the influence maximisation algorithm (as shown in Fig.4) to select cluster heads, and its pseudo-code is as follow:

**ALGORITHM 1**:Cluster Head Selection
**Input**: number of nodes num;find nodes k.
**Output**: K nodes S[].

```
1.  ClusterSelection(num,k){
2.      FuctionFind(x){
3.          //calculate the maximum number of nodes affected by the nc
4.          BFS(x)   //wide search,count the number of nodes affected
5.      }
6.      For x := 1 To num {     //all nodes are traversed
7.          //satisfies the condition to update S set
8.          S = max ( Max， Find(x) )
9.      }
10.     return S;
11. }
```

The influence maximisation algorithm adopts the greedy strategy. It puts a node into the set and records the number of nodes that can be affected by all nodes in the set. After that, it puts the new nodes into the set in turn. If the number of nodes that can be affected by all nodes in the set increases or the number of nodes exceeds the standard due to the addition of new nodes, the nodes with the least influence in the set will be deleted. The node in the final set is the node with the largest influence required.

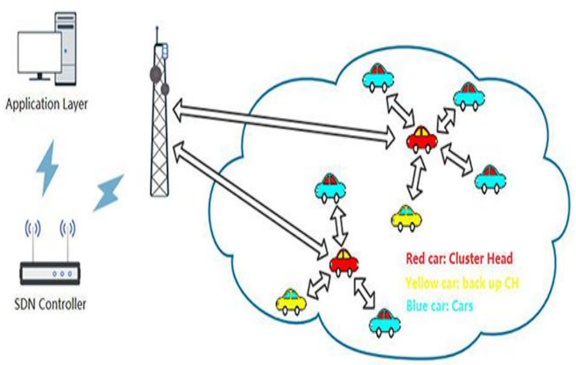


Fig. 3. Rough breakdown of the cluster

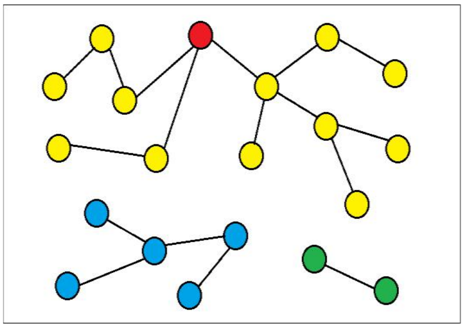

Fig. 4. The influence maximisation algorithm was used to select cluster heads

As shown in Fig.4, there are three clusters. We first give a specific positive integer k as one of the inputs of Algorithm 1. Secondly, the set S containing kinitial nodes is selected from the network (line 2 of Algorithm 1), so that the k initial nodes can affect other nodes, and the final number of affected nodes &(S) is maximised (line 8 of Algorithm 1). Finally, the red node (optimal cluster head) is selected by using the relevant information collected by the controller before and the calculation equation, which is defined by:

$$\max\{\&(s),\ |s| = k, s \in V\} \tag{1}$$

Then the controller can directly communicate with the cluster head.

The unique advantages of dual cluster heads are concluded as follows. When vehicles in the cluster communicate, the cluster head will obtain the relevant information of other vehicles in the cluster. Any two vehicles can communicate directly through the cluster head rather than through the controller to obtain the next hop information. Therefore, inner cluster communication is achieved which reduces the uplink and downlink routing overheads from/to controller. In contrast, only if the vehicles in two different clusters communicate with each other, the cluster heads of the two clusters will exchange the flow table and obtain the relevant vehicle information through the controller, where the flow table will be transmitted to the low-level cluster heads and then relayed to the corresponding nodes for transmitting data packets. At the same time, when nodes move from one cluster to another, only the nodes in the cluster need to update information, which reduces the amount of the stored information and overhead per node.

*B. Double Cluster Head Scheme*

In this subsection, we will introduce a double cluster head routing scheme which intends to improve the robustness of the network further. Recall Fig.2, in that figure, an example is illustrated where *V2*(*CH*) in cluster 1 communicates with the base station and the controller. Other vehicles in the cluster communicate through it using the IEEE 802.11p interface, reducing network computing cost and routing overhead. However, this type of single-cluster head structure may be a single point of failure. We assume that there could be an unexpected or unpredictable incident such as the cluster head being damaged or lost, then the role of the cluster head will disappear, returning to the traditional communication. Consequently, double cluster heads for designing is equally important.

As shown in Fig.5, the existing CH always sends FCD data [26] to the standby CH. If the existing cluster head normally leaves without any issues, the backup cluster head will immediately work as the new cluster head of the cluster. Then we will select a new backup cluster head applying the influence maximisation algorithm so that the backup CH can be able to take responsibilities seamlessly.

### C. Our Algorithm as an Example

Recall the Fig.2. It illustrates the compositions of *IMCR* and how it works. A few important components will be described in detail as follows:

*1) Clustering.* The vehicles in Fig.2 are divided into two clusters by geographic locations, cluster 1 (*V1 ~ V5*) and cluster 2 (*V9 ~ V13*). Clustering improves the scalability of the network and makes the network more flexible.

*2) Double Cluster Heads.* Taking cluster 1 as an example, red car (*V2*) and yellow car (*V4*) in Fig.2 are selected as the cluster head and the backup cluster head respectively with the influence maximisation algorithm. *V4* exchanges status information with *V2* all the time, so that it can replace *V2* to continue communicating whenever there is an issue with *V2*.

*3) Intra-cluster Communication* (Communications of vehicles in the cluster). For example, vehicles in cluster 1 send and receive data through IEEE 802.11p to *V2*, and then *V2* communicates with the external controller and the base station, which saves many spectrum resources and reduces the burden of the network.

*4) Inter-cluster Communication* (Communications of vehicles outside the cluster). In the case of cluster 2, *V8* communicates directly with the base station and the controller. When *V8* intends to send packets to other vehicles in cluster 2 such as *V13*, it first speaks with the controller. The controller calculates the flow table from *V8* to *V13* and replies *V13*. At the same time, the flow table is sent to the cluster head V9 of cluster 2. *V9* then starts to send data packets to *V13* by following the flow table.

To sum up, the *Influence Maximisation-based Cluster Routing Algorithm for SDVN* reduces the network overhead and improves the network robustness, with the structure of the double cluster head.

## V. EXPERIMENT AND PERFORMANCE EVALUATION

To prove the superiority of *IMCR*, we conduct simulation experiments in CodeBlocks with real road network data and floating vehicle trajectory data. The overall construction of experiments is listed as follows. We first apply the influence maximisation algorithm to select the most suitable vehicles as the cluster head. Then, the experimental data generated by the traffic generator SUMO [27] are sorted into a timing matrix and put into the SDVN controller. We realise the framework of communication request and reply between the controller and vehicles with code simulation to obtain the topology of the whole network.

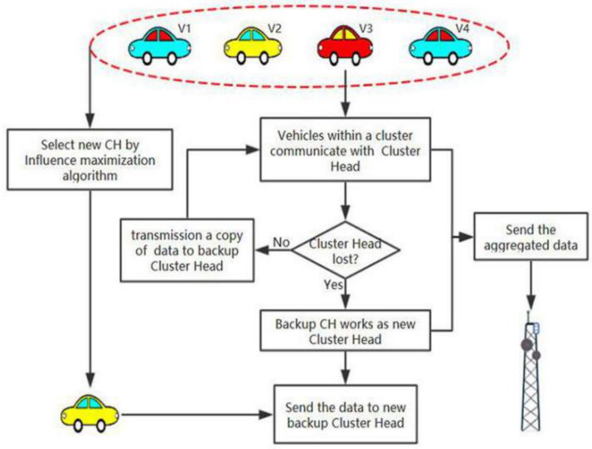

Fig. 5. The design principle of double cluster head

### A. Concrete Implementation of the Experiments

In this experiment, we focus on the vehicle communication within the scope of a cluster. We used SUMO to generate vehicle nodes within the map of 1650 m × 1933 m, with the number of nodes ranging from 10 to 280. Simulation time is 100 seconds. Firstly, the initialization process is carried out to obtain the location information of all vehicle nodes and the relevant communication relationship. Then, the vehicle nodes update the data in real time, and send the updated status information to the corresponding cluster head, which then sends it to the controller. Among them, the cluster heads were selected by the influence maximisation algorithm. In this way, we achieved the maintenance of cluster.

To prove the superiority of this algorithm, we have carried out experiments and compared the results under three kinds of structures, clusterless, single cluster head and double cluster heads. In addition, we also analyzed the algorithm based on speed and signal-to-noise ratio (SNR) [16] for the cluster head selection. The result shows that the influence maximisation algorithm has batter advantage.

For the clusterless structure, we randomly selected a vehicle node to transmit information between vehicles. For the single cluster, we also applied the breadth-first traversal algorithm of graph to calculate the number of hops in the influence maximisation. In the dual cluster structure, we used the dual thread simulation. When the existing cluster head is lost, the cluster head can be changed dynamically, so as to carry out the data communication. We used the performance indexes of delay and packet loss rate to measure the communication efficiency. We simulated the number of vehicles receiving data through the queue. The queue stores cluster-head nodes, and then the nodes receiving the information are continuously enqueued. The delay and packet loss rate are dynamically updated according to the node position and number of hops. When the queue is empty, the simulation ends and the experimental data is displayed.

### B. Comparative Analysis of Experimental Results

In order to evaluate the performance of the proposed *IMCR* algorithm and the traditional method, we carried out the simulation. The experimental results are generated from CodeBlocks, and the pictures are printed by MATLAB. The experimental results are shown in Fig.6, Fig.7 and Fig.8. Because of the packet loss rate can show the stability of data transmission and the delay time can reflect the current network congestion, thus in the comparative analysis of the experimental results, we adopted two parameters as the measurement standard of network communication quality, namely, time delay and packet loss rate.

One contrast is between the traditional networks and the cluster structure. With vehicle nodes increasing, respectively, we compared with no clusters, single cluster and double clusters for the influence of time delay and packet loss rate.

#### 1) Time Delay

Fig.6 shows the comparison of time delay versus vehicle numbers. As a reflection of network congestion, time delay can provide more accurate network communication performance. It is defined as the ratio between the maximum number of transfer layers and the time of each hop, and the equation is defined as follows:

$$maxLayer = max(cars.layer, maxLayer) \quad (2)$$

$$Time\_delay = maxLayer * jump\_time \quad (3)$$

Here, max is the function with selecting the biggest value and cars.layer is the maximum number of layers of the current vehicle nodes. The lower the maximum number of transfer layers, the longer this CH would be stay in the cluster and serve better; Similarly, the shorter the time of each hop, the smaller the overall delay, and the faster the packet is transmitted.

As can be seen from Fig.6, when the number of vehicles in the network is relatively small, the delay of both the traditional network and the cluster structure is similar. However, the double-cluster head structure also produces the least delay. With more data arrivals and vehicle nodes increased, the delay of double-cluster structure was also lower than other two structures. It is obvious that the design of double cluster head can produce lower processing delay, reduce the uplink overhead and have better performance. This is because in this structure, when the existing cluster head fails, the standby cluster head can quickly replace the original cluster head to continue communicating and reduce the blocking probability of the network. Similarly, it can be seen from Fig.7 that the structure with clusters is much better than the traditional structure in terms of packet loss rate.

#### 2) Pack et Loss Rate

In Fig.7, we can observe that generally, the possibility of packet loss rate increases when there are more arriving vehicles, which is because that more data interaction makes cellular resource burden bigger. In this part, the packet loss rate is defined by:

$$packetLoss = (reallyNum - numPackets) / reallyNum \quad (4)$$

Here the reallyNum is the actual number of packets and numPackets is the packet that are sent successfully. As shown in Fig.7, it can be clearly seen that at each point, compared with no clusters and cluster scheme, the double-cluster structure has the lowest packet loss rate. So it can effectively increase the stability and the equality of data transmission.

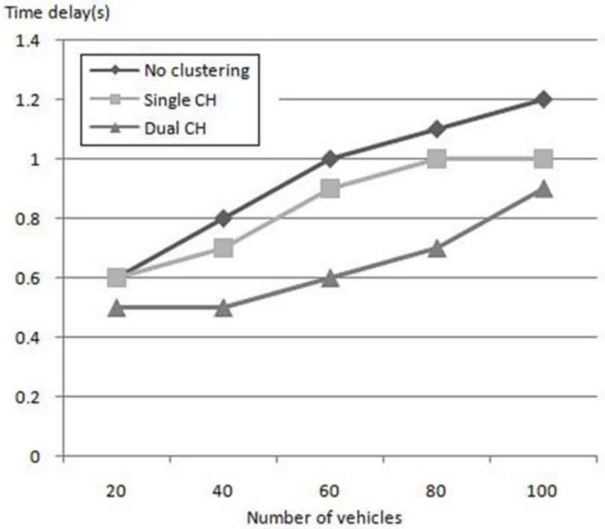


Fig.6. Simulation results of different cluster structures for packet loss rate

The other contrast is between the influence maximisation algorithm and the algorithm based on speed and signal-to-noise ratio (SNR)[16]. We still considered the influence of vehicles increasing on the loss rate, where velocity is calculated by the following equation:

$$aveSpeed = totalSpeed / numCars \quad (5)$$

Here the totalSpeed is the sum of all vehicle speeds in a cluster at a given time, numCars is the total number of vehicles, and aveSpeed is the average speed of vehicles. The results were showed in Fig.8. We can see that when the number of vehicle nodes is the same, the cluster heads selected by the influence maximisation have better advantages, which can effectively reduce the rate of packet loss, compared with the algorithm based on speed and signal-to-noise ratio (SNR).

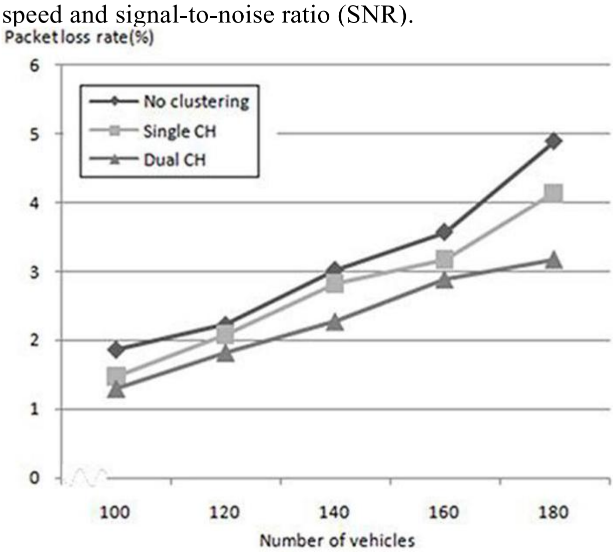


Fig.7. Simulation results of different cluster structures for packet loss rate

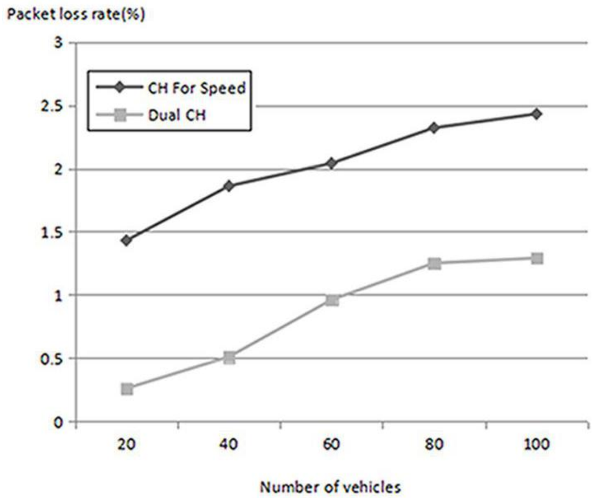


Fig.8. Simulation results of *IMCR* vs Speed for packet loss rate

## VI. CONCLUSION

The prompt progress of high and new technology has brought an urgent need for vehicular communication. Traditional network architecture can no longer meet the specific needs of people. In this paper, we apply a new network architecture SDVN to vehicular communication. SDVN has more advantages than VANET, such as programmable, centralised control and flexibility. It decouples the data plane from the control plane, facilitating network management. Meanwhile, the communication between vehicles through IEEE 802.11p connection also saves abundant cellular resources. Besides, we also propose an *Influence Maximisation-based Cluster Routing Algorithm for SDVN (IMCR)*, which reduces the signal processing overhead and improves the communication quality. However, although this method solves the existing issues, it still faces some challenges. For example, how to achieve fast and reliable service quality of SDVN communication and how to precisely apply influence maximisation in high-density static social networks to the low and high-speed dynamic topology SDVN. These are urgent issues to be solved in the future.

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