The Key Technology of High-Definition Maps Distribution Based on Edge Computing

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Abstract: The High-Definition map (HD map) is a key technology to achieve automatic driving above the grade of L3, with the amount of data comes to more than 10^5 times that of traditional navigation map. With the arrival of 5G communication and the rapid development of Internet of Things, each autonomous vehicle will request HD map service by accessing the Internet. The service of traditional navigation map under "cloud-end" mode may not be well adapted to future HD map application, so the paper proposes a MEC proposal for HD map application, deploying HD map server under "cloud-edge-end" mode to mitigate the high latency and improve low reliability caused by the faraway physical distance rather than "cloud-end" mode. The HD map is divided according to the latitude and longitude regions, being pushed to local edge computing node servers respectively to realize the interaction between autonomous vehicles and edge servers, which makes more convenient and reliable HD map services available. The experimental results show that the proposed proposal can cut off the communication delay effectively, ensuring the reliability of the HD map service, and providing high-quality HD map service for autonomous vehicles.

Key words: Automatic driving, HD map, edge computing, data distribution.

1. Introduction

With the sustained expansion of global autonomous driving industry, the research on HD map [1] is gradually emerging. In the circumstance of automatic driving above L3 [2], HD map is an indispensable core technology which assists vehicles to complete automatic driving. It can guarantee the security and reliability of automatic driving well with its formidable perception to the driving environment. At present, autonomous vehicles mainly detect surrounding environment with on-board sensors, and a small number of enterprises have begun to explore the construction of road infrastructures which can communicate with autonomous vehicles, trying to utilize RSU (Road Side Unit) [3] in assisting automatic driving.

Many companies in China and other countries have begun the research on HD maps. In particular, those companies which do research on autonomous vehicles are exploring their own exclusive HD maps, the usual forms of navigation map application are mainly "cloud-end", and "Client/Server" or "Browser/Server" architecture is adapted. But with the advent of 5G era and the rapid development of the Internet of things, every autonomous vehicle will be connected to the Internet, which will generate massive real-time data in exponential growth. In this case, traditional "cloud-end" mode [4] will not be able to support application service programs for HD maps efficiently due to the high latency in data transmission, caused by the faraway physical distance and network distance between autonomous vehicles and cloud computing center. Fig. 1

shows the traditional map navigation application mode.

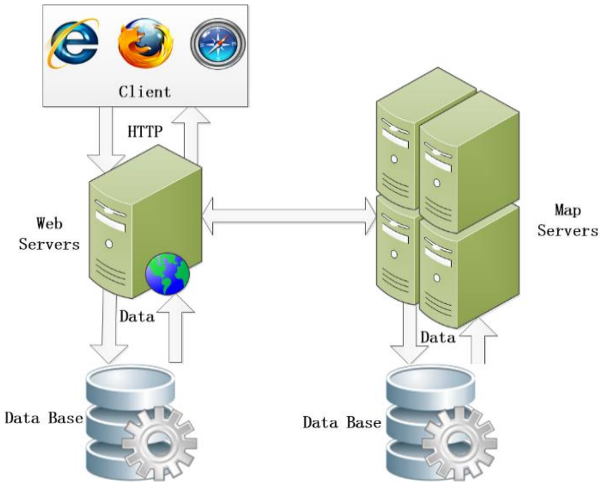

Fig. 1. Traditional map navigation application mode.

This paper aims to propose a Multi-access Edge Computing(MEC) system for HD map applications, which mitigates the high latency and improves low reliability in traditional “cloud-end” mode with the form of “cloud-edge-end” mode. Traditional HD map applications need to make requests to the cloud server to obtain map data. However, due to the long distance and numerous access requests, the communication efficiency will be interfered by various uncertain factors such as server load, network environment, and propagation path. As a result, the real-time performance of HD map services cannot be guaranteed, which may even affect the safety of automatic driving. In this paper, combined with the emerging concept of MEC, the HD map data required for autonomous vehicles will be distributed to the edge computing nodes in each region according to the latitude and longitude. The application only needs to communicate with HD map server deployed in edge computing node nearby to request HD map data. In this way, the “cloud-edge-end” mode may meet the requirements of real-time and reliability of HD map application to some extent, which is of great significance for the research of automatic driving technology.

Section 1 of this paper gives a brief introduction to the work to be done. Section 2 provides some related background knowledge needed in the article, including automatic driving technology, HD map applications, MEC, etc. Section 3 introduces the framework structure and specific technical details of MEC proposal for HD map applications. Section 4 analyzes the experimental test results. Finally, the paper summarizes the full text and discusses the difficulties worthy of research in the future

2. Background Information

This section outlines the technologies related to the content of the paper.

2.1. Automatic Driving

Automatic driving technology [5] is a comprehensive and complex project involving technologies covering various aspects of hardware and software, such as sensor technology, artificial intelligence algorithms, automatic navigation and control, etc. Since 1970, the developed countries have started the research of automatic driving, which are divided into 6 grades of 0–5. At present, the autonomous vehicles researched by some companies can reach level 3 (L3), and can reach level 4 with the assistance of specific environment and infrastructure. When autonomous vehicles are driving on the road, the traffic data of this section must be obtained, including road route, road slope, curve length and curvature, traffic signs, traffic indicators, etc., and the real-time road condition of the current road section as well. HD map can provide relevant information sufficiently, so it is the basis for the autonomous vehicle to put into mass production and actual operation.

Nowadays, Google, Lexus, Volvo and other large enterprises are at the forefront of the research on automatic driving technology. The autonomous vehicle developed by Google grasps real-time road conditions by using Google maps, and controls more detailed conditions by using car camera, radar sensor, laser rangefinder, such as braking, acceleration, steering, etc. German researchers have equipped autonomous vehicles with LIDAR, AI algorithm terminals, GPS and other devices, so that they can drive independently on the road.

China's research on automatic driving technology developed rapidly even though start from scratch. Large enterprises such as Chang'an, Geely and BYD, as well as Internet companies like Tencent, Baidu and Ali, are committed to the research and development of autonomous vehicles. At the same time, several provinces and cities in China have taken the lead in the infrastructure construction of auxiliary automatic driving technology. At the beginning of 2020, the first 100 km intelligent highway built by Hunan Xiangjiang Intelligent Technology Innovation Center Co., Ltd, will be put into trial operation in Xiangjiang new area of Hunan Province. The construction of smart highway network is to build a large-scale national urban intelligent network of vehicle application test area based on 5G-V2X vehicle road coordination. The infrastructure in this area can meet the requirements of automatic driving above L3 level

2.2. C-V2X Overview

In the process of automatic driving, the communication between vehicles is generally vehicle wireless communication [6] (Vehicle to Everything, V2X), and the communication between the vehicle and the base station is C-V2X [7]. Vehicle to everything (V2X) refers to the information communication technology that vehicles connect with anything, in which V represents vehicles and X represents any object that interacts with vehicles, moreover, X can be vehicles, people, traffic roadsides infrastructure and networks. V2X information interaction modes include vehicle to vehicle (V2V), vehicle to infrastructure, (V2I), vehicle to pedestrian (V2P), vehicle to network (V2N). As shown in Fig. 2, the main application scenario studied in this paper is vehicle to network interaction (V2N), focusing on the communication between vehicle and edge computing server.

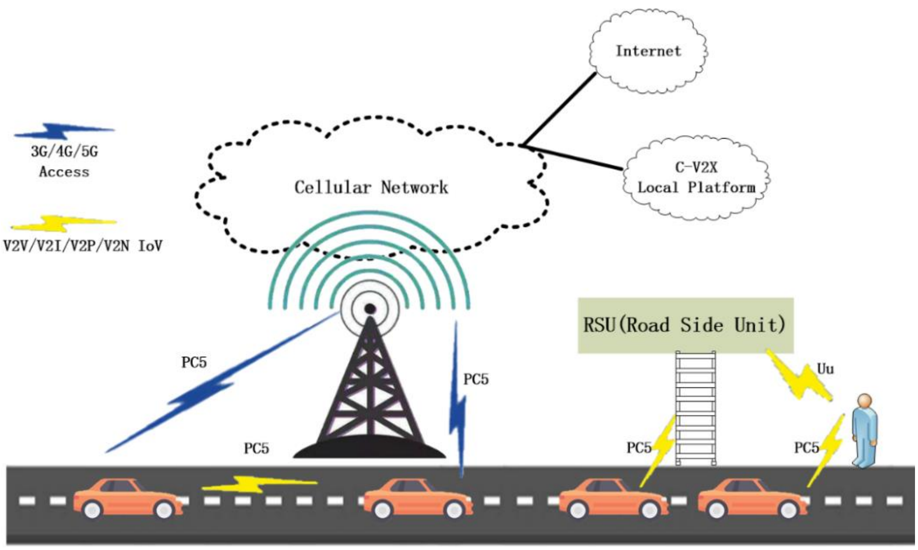

Fig. 2. Classification of vehicle wireless communication technology.

C in C-V2X refers to cellular, which is a vehicle wireless communication technology based on cellular network communication technology such as 3G/4G/5G, including two kinds of communication interfaces: one is the short-distance direct communication interface (PC5) between vehicles, people and roads, the other is the communication interface (Uu) between terminal and base station, which can realize long-distance and more wide range reliable communication. The terminal equipment (such as vehicle terminal) supporting C-V2X can use Uu Interface under the control of cellular network when it is in cellular network coverage; PC5 interface can be used for V2X communication whether there is network coverage or not. C-V2X combines Uu and PC5 interface to support with each other, which is used for V2X service transmission to form effective redundancy to ensure communication reliability. This paper mainly focuses on the HD map service with ultra-low delay and ultra-high transmission reliability requirements, and studies the overall framework and implementation scheme of supporting mobile edge computing (MEC) technology under the PC5 interface of C-V2X.

2.3. Edge Computing

With the number of devices connected to the Internet has increased dramatically, the amount of data generated by those devices has soared up exceedingly. By 2021 [8], it is estimated by Cisco Global Cloud Index that the global cloud data center traffic will increase from $6ZB$ in 2016 to $19.5ZB$. The report also found that by 2021, cloud computing will account for 95% of all data center traffic, compared with 88% in 2016. These data created by IoT will be stored, processed, analyzed, and acted upon close to, or at the edge of the network. Therefore, processing data only relying on cloud server or cloud computing will be far from the requirements of users. In the era of Internet of things, strict requirements are put forward for the delay and security of data processing. When the growth rate of data is much higher than the growth rate of network bandwidth, the complex network environment makes it difficult to improve the network delay. The means of network edge computing has emerged as an auxiliary method [9]. Fig. 3 shows the general cloud computing model. Data is produced by terminal devices and sent directly to the cloud server. Smart phones, personal computers, autonomous cars, etc. send computing requests to the cloud server and obtain services. The authors of the accepted manuscripts will be given a copyright form and the form should accompany your final submission.

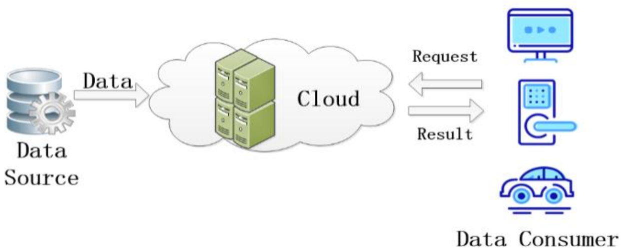

Fig. 3. General cloud computing model.

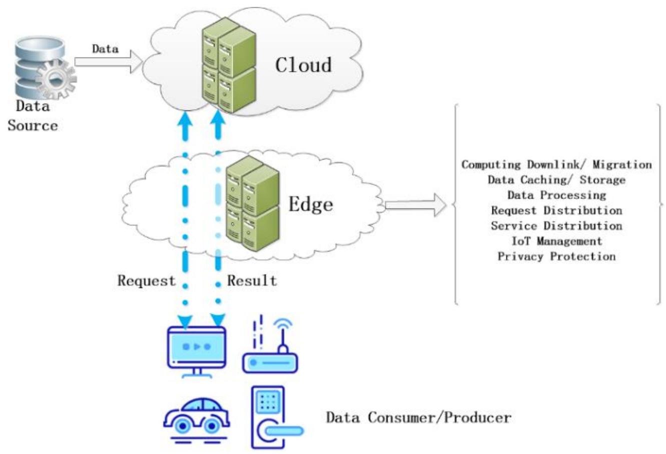

Fig. 4. General edge computing model.

Carnegie Mellon University describes edge computing [10] as: deploying compute storage nodes on the edge of the network closer to the user and device. In fact, the essence of the edge compute node is the server. Moreover, it's been deployed on the front side which can replace the cloud server to relieve the pressure of data processing. This role is particularly important in the context of the 5G era. In the big data environment, the network bandwidth is usually overloaded and the computing resources are easy to be wasted. Therefore, certain computing tasks need to be offloaded [11] to the edge. Fig. 4 shows a general model for edge computing.

2.4. Automatic Driving with MEC

The automatic driving is built on the C-V2X communication [12]. The integration concept of MEC [13] and automatic driving is to deploy the C-V2X service on the MEC platform, and support the "human-vehicle-road-cloud" cooperative interaction, which can cut off the delay in point-to-point data transmission, ease the computing and storage pressure of the terminal or roadside intelligent facilities, cut back on the network load caused by massive data backhaul, and provide high-quality services with local characteristics. The scene view of the MEC and C-V2X is shown in Fig. 5.

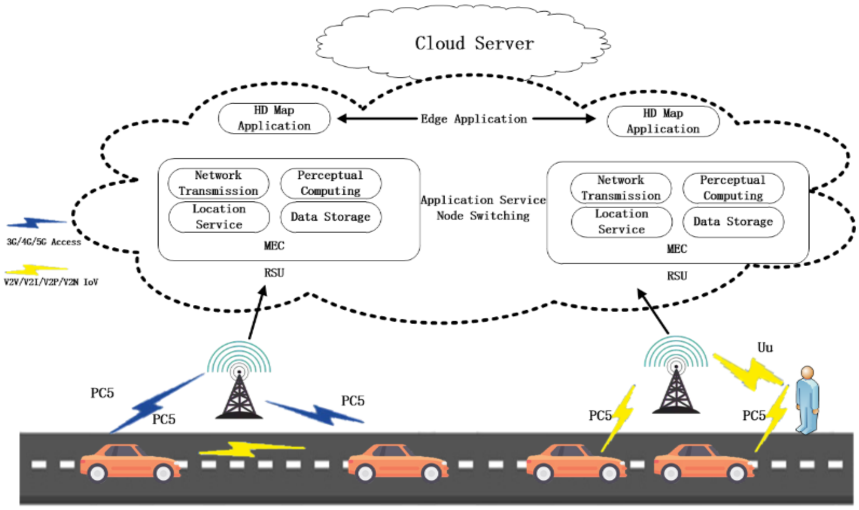

Fig. 5. The scene view of MEC merges with C-V2X.

This paper focuses on the scene of interaction between single vehicle and MEC, which doesn't involve the interaction between vehicle-to-vehicle or vehicle-to-person. In the process of automatic driving, the function of HD map application can be realized by interaction between single vehicle and MEC. As shown in Fig. 6.

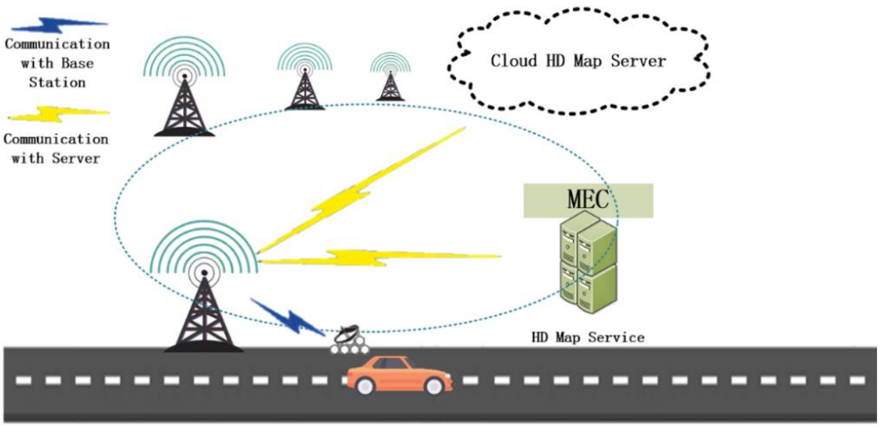

Fig. 6. Schematic diagram of interaction scene between single vehicle and MEC.

In the process of automatic driving, the autonomous vehicle communicates with HD map server on the cloud and the edge side through the roadside IoV (Internet of Vehicle) base station to get HD map service. The specific communication procedure is described in detail in Section 3. MEC is the edge node for content distribution, which is used to store dynamic HD maps, distribute HD map information, reduce data transmission delay and reduce the pressure on the core network transmission bandwidth.

2.5. High-Definition Map

High-Definition map [14] is a combination of high-precision, high-dimensional, high-real-time map data. Compared with the data error of electronic maps, the relative accuracy error of HD maps does not exceed $20cm$. Unlike traditional electronic maps, HD maps contain a large amount of driving assistance information. The most important of these is the accurate 3D representation of the road network, such as the intersection layout and the location of the landmarks. HD maps also contain a lot of semantic information, including signal color definition, road speed limit information, vehicle turn start position, etc. It's currently the most effective solution for complex traffic environments that HD map combined with sensors, including HD map matching and positioning, auxiliary environment perception, and assisted decision-making. [15] At present, Google Car [16] has completed the automatic driving HD map mapping that accumulated more than $1931212.8km$.

- HD map positioning: the accuracy of absolute coordinate in HD map is high. The sensor verifies and compares the information sensed by the car with that of high precision map, providing a reference for the car to determine its position, direction and other information at a high precision level. It's an important prerequisite that the autonomous vehicle carries out automatic driving.
- Auxiliary environment perception: marking the detailed road information on the high-precision map, and assisting the vehicle to verify in the perception process. For example, when the vehicle sensor senses the potholes on the road ahead, which can be compared with the data in the high-precision map. If the same potholes are marked in the map, it can play a role of verification and judgment.
- Assisting decision making and planning: HD map can supplement the parts that cannot be detected by sensors. Real-time situation detection and external information feedback may assist us with more comprehensive accessing to the surrounding environment information. It can help autonomous vehicle predicts road complex information, such as slope, curvature, heading and so on, so as to avoid potential risks better. Also, it can effectively provide the latest road conditions for automatic driving and realize lane level path planning. Especially in the aspect of global path planning, there are places that cannot be detected by sensors, and it is particularly an important supplement that the abundant road elements in HD map.

2.6. HD Map with MEC

The data volume of HD maps [17] is 105 times or more of that of ordinary maps. At present, the total amount of HD map data that NavInfo has drawn has exceeded 4PB, and it is still growing at a rate of $2.8TB$ per day. With the development of services such as IoV and automatic driving, the growth rate of data scale is bound to boom. The centralized big data processing model with cloud computing as the core has not satisfied the demand. With the rapid development of the IoT and 5G communication technology, the computational method of cloud-edge collaboration—Edge Computing is proposed.

3. System Framework

In order to solve the problem of high latency and low reliability of traditional map navigation in the “cloud-end” application mode, this section proposes a MEC system for HD map distribution, and will describe how HD maps in “cloud-edge-end” application mode works under the framework structure and the functions of each layer in detail.

3.1. System Scheme

Since the map server in the cloud is far away from the vehicle in physical distance and network distance, and the vehicle interacts with the cloud server after connecting to the Internet through the access network provided by the operator, the instability of the Internet environment exacerbates the issues of high latency and low reliability about HD map service. Generally speaking, in the traditional map mode, the vehicle-mounted client of the autonomous vehicle needs to download $100KB{\sim}250KB$ of data from the map server to complete the path planning; in the mode of HD map providing service, the amount of data is more than 10^5 times, so vehicle-mounted client needs to download more than $25GB$ of data to complete the path planning. In such cases, it's preferable to propose an edge computing node to push the server providing the HD map service to the side close to the data consumer (i.e. the autonomous vehicle), so that the autonomous vehicle can download data and get services in a shorter physical distance and network distance. Therefore, this paper designs a MEC system for HD map applications, and drops the function of providing services by the cloud map server to the edge computing node. The local HD map data is distributed to edge computing nodes within the region according to the latitude and longitude. In the process of automatic driving, the vehicle only needs to communicate with the local edge computing nodes to obtain the corresponding HD map service. Moreover, the HD map server settled in edge computing node is consist of cluster in each region, so it is much more stable.

3.2. System Logic Structure

As shown in Fig. 7, the MEC system for HD map application is logically divided into three layers, which is the presentation layer, the application layer and the data layer from top to bottom. The application layer includes the web server, the HD map server and the spatial data engine. The web server is responsible for receiving and forwarding the requests sent by the client and returning the results processed by server to the client; The HD map server is in the form of cluster deployed in each edge computing node, which can improve the system performance; The spatial data engine is responsible for reading the spatial data from the spatial database or file and writing the modified data to the database or file for saving. The web server and map server of the application layer and the database of the data layer are deployed on the MEC node. The autonomous vehicle communicates directly with the nearest computing node cluster by accessing the operator network.

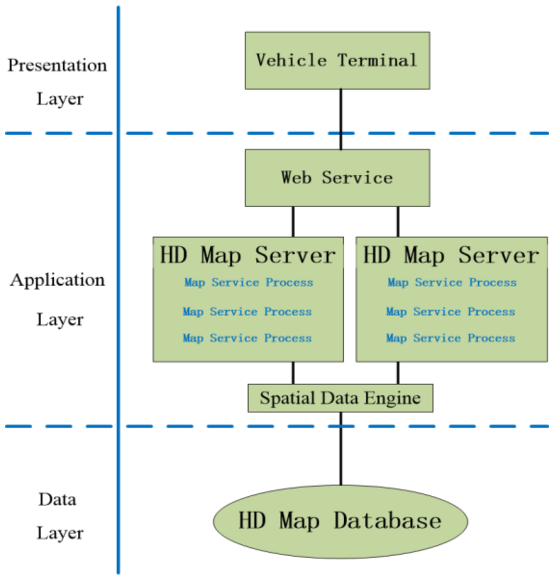

Fig. 7. Logic Structure of MEC system for HD map application.

3.3. System Architecture and Servers Deployment

The HD map server is deployed in a cloud-edge collaborative form. It's generally divided into two parts: the cloud and the edge. The cloud consists of a cloud web server, a cloud HD map server, and a corresponding database. The edge side is composed of edge web servers, edge HD map servers and corresponding database. The deployment is shown in Fig. 8.

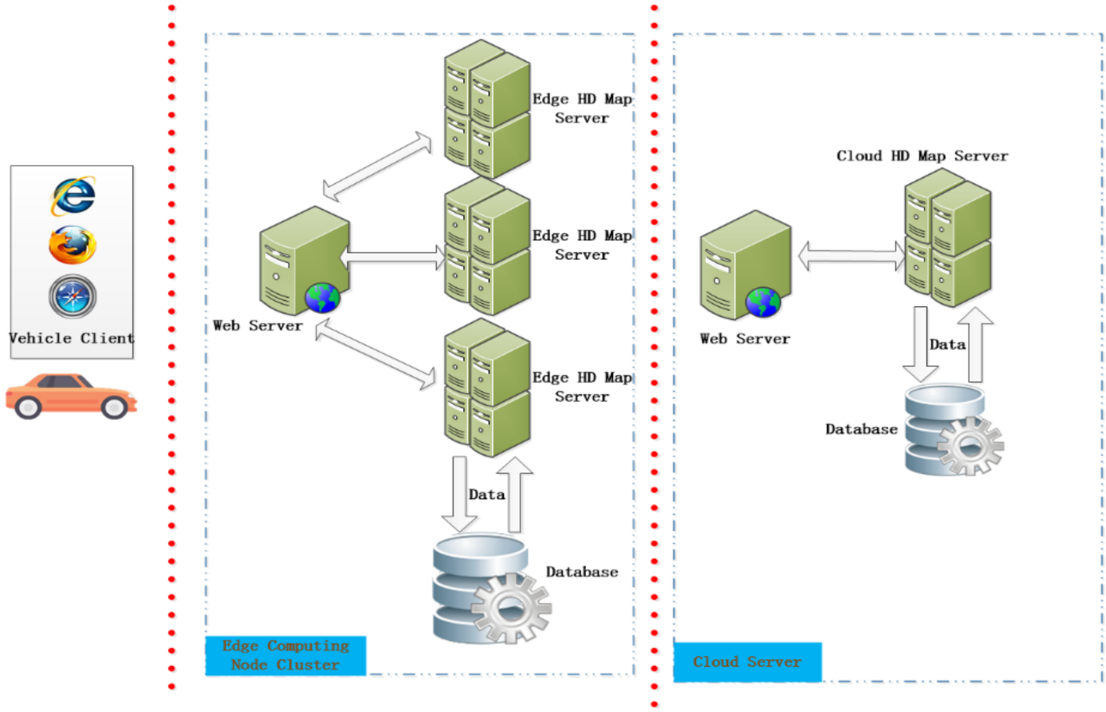

Fig. 8. The HD map servers deployment based on MEC.

The HD map servers deployed in cloud-edge collaborative form has the following functions as a whole:

- The access of large-scale/heterogeneous vehicle equipment, gateways and edge nodes.
- A large number of map data could be aggregated and processed for use in map servers.
- Vehicle security and identification services.
- Support remote command to the vehicles.
- Enable cloud-to-edge application orchestration, deployment and configuration.
- Provides data storage, data distribution, event management, API management, and data analysis capabilities for edge application development.

The cloud can provide the following services:

- The initial identification and registration of the vehicle into the network.
- Management of edge HD map servers, including assigning IP addresses, adding or subtracting edge computing nodes.
- Management of global HD map data, including distributing data to the edge and correcting HD map data in time based on the difference information from edge detected.

The edge side can provide the following services:

- Respond to HD map service requests for autonomous vehicles and provide them with the required services.
- Manage HD map data stored, and compare real-time data with inventory data according to certain judgment rules.
- Support real-time roads' situation analysis after on-board sensors collecting roads' data.

- Ability to upload real-time roads' conditions to cloud servers to assist in high-precision map data correction.

In addition to storing the global HD map data, the cloud web server is also responsible for delivering map data to the edge computing nodes of the region according to the latitude and longitude. The edge computing nodes in the city are deployed in the RSUs, which are set up on the expressway at intervals of $2km$. (Next subsection will explain the reasons for deploying at this distance.)

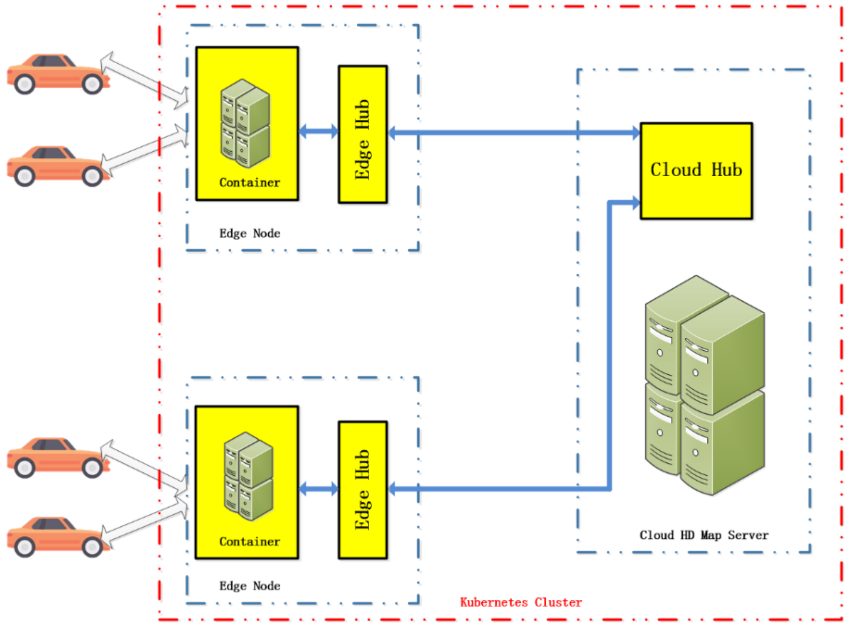

Fig. 9. The deployment model of KubeEdge.

KubeEdge is the first open intelligent edge platform based on Kubernetes [18] extension to provide cloud-edge collaboration. It's also the open source project is hosted by the Cloud Native Computing Foundation (CNCF) in the smart edge field, which can solve the server deployment problem of this paper. The deployment model is shown in Fig. 9. This is a completely decentralized deployment model, where the management platform is deployed in the cloud and the edge computing nodes can run Kubernetes agents without much resources. The cloud HD map server and edge HD map server cooperate through network communication. From the perspective of Kubernetes, “Edge Nodes + Cloud” constitutes a complete Kubernetes cluster [19]. This layout model can meet the deployment requirements of HD map content distribution scenarios for automatic driving. KubeEdge manages the addition, deletion, and change of edge nodes, devices, and workloads in the cloud through the Kubernetes standard API. System upgrading and application updating of edge nodes can be directly sent from the cloud to improve edge operation and maintenance efficiency.

In order to avoid the problem of edge computing node load balancing during the driving process, this paper uses HD map server distributed cluster deployment to deal with high concurrency pressure. The cluster of the MEC system for HD map consists of one web server and several HD map servers in the latitude and longitude of the region, all deployed on the edge computing nodes. According to the existing expressway, the density of one edge computing node may be deployed every $2km$, which can satisfy the load demand well. Fig. 10 shows the realization of the HD map server cluster mode in RSU. We can see that on the road of $4km$, a total of 2 RSUs are deployed, which consists of 2 MEC nodes. Each MEC node includes 2 HD map servers, one web server, and one database server. They are connected by a high-speed interconnected network and a high-speed intelligent switch, and nodes are also connected through network. The web server is responsible for listening to the request and forwarding request sent by the client, and returns the result to the client; the

HD map server is responsible for processing the request, and returns the processing result to the web server; the database server is responsible for storing the HD map data. A dedicated IoV base station is deployed at the front end of each MEC node to receive the requests sent by the on-board unit of the autonomous vehicles and forward them to the web server.

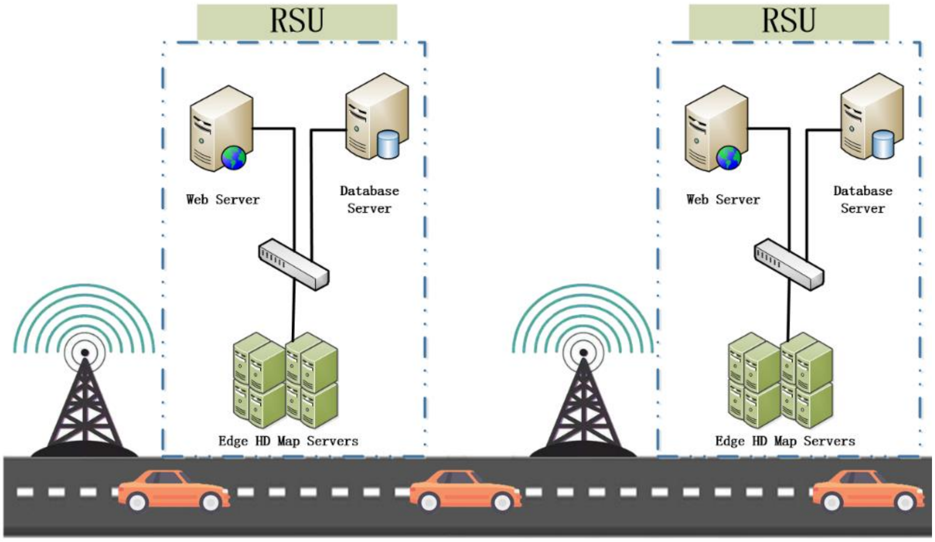

Fig. 10. The RSUs deployment on the road.

3.4. Distribution of HD Map

The core idea of this paper is the distribution of HD map data. After the full-scale HD map in the cloud being divided according to the latitude and longitude division, the map will be distributed to the local edge HD map server cluster, which is used for automatic driving.

3.4.1. RSU development

The actual distance is about 111km when the latitude is 1 degree on the meridian; on the latitude, the actual distance is 111×cos θkm (where θ represents the corresponding latitude) while the longitude is 1 degree. Therefore, this paper deploys edge computing nodes according to the distribution of latitude and longitude lines. Every edge computing node is arranged in the interval of 2km on the road since 1 degree is equally divided into 60 points, which may be suitable. An edge HD map server in an edge computing node is sufficient to cover HD maps within an area of 4 square kilometers.

3.4.2. The process of HD map distribution

HD map distribution can be solved by the horizontal fragmentation technology [20] of the map database, and the cloud is responsible for managing the data in the edge computing node, including updating and proofreading. It is easy to achieve clipping the vector map [21] by GIS (Geographic Information System) [22]. When all infrastructures (servers, databases, etc.) are placed in the framework of KubeEdge, the cloud will listen to the cache requests of all edge computing nodes, which should include the number and latitude and longitude of edge computing nodes. In the cloud, there should be a table maintained which contains the correspondence of edge computing nodes and latitude and longitude. The cloud will deliver the clipped HD map back to edge computing nodes in sequence according to the table.

3.5. System Communication Process

In the MEC system for HD map, the key problem in getting HD map services is how to obtain IP addresses of the edge HD map servers. The general flow is shown in Fig. 11.

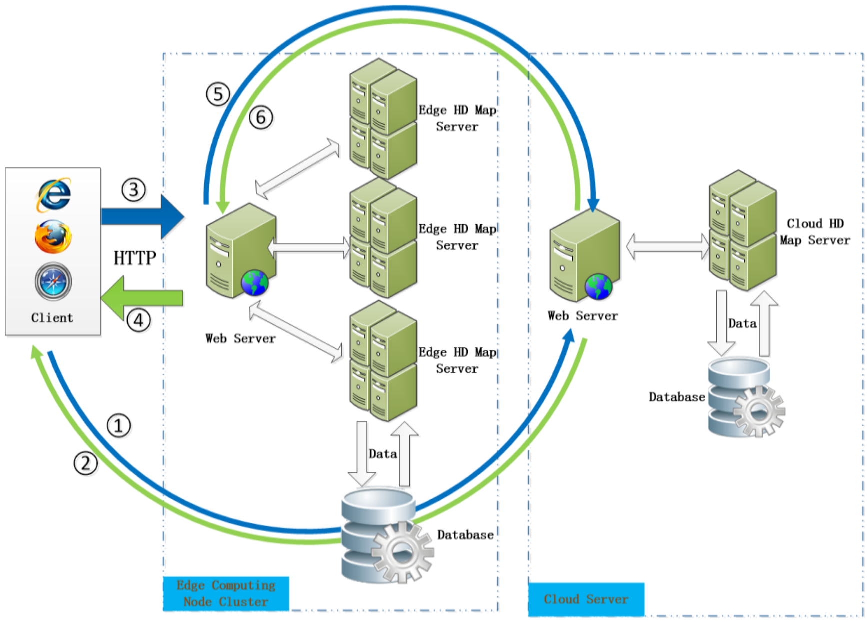

Fig. 11. System architecture and communication process.

1) Before the vehicle starts to drive automatically, it accesses the Internet through operator network, and will be assigned a fixed IP. After that, the vehicle sends a request to the cloud web server in the IP assigned, which includes the latitude and longitude information currently located by the vehicle. At the same time, according to the fixed position information from vehicle HD positioning module, the vehicle will apply for the path planning to the cloud HD map server, aiming to complete the path planning from start point to end point of the automatic driving.

2) The cloud web server returns the IP address of the edge HD map server to the vehicle according to the location of latitude and longitude, and notifies the server of the IP address of the vehicle. This is equivalent to a registration and verification process of the vehicle identity. After that, the vehicle doesn't need to be verified again to communicate with edge HD map server. As long as the service request is made by the vehicle IP, the server responds directly. At this time, the cloud HD map server will return the map data of the area where the path is planned for automatic driving.

It should be noted that the map data returned by the cloud HD map server doesn't contain HD content, which is no different from the traditional map data. The purpose of this design is to reduce network traffic, enable the vehicle to complete path planning more quickly, and start automatic driving.

3) The vehicle accesses the edge HD map server in the local area through the IP address returned by the cloud web server, and the HTTP request sent by the vehicle is forwarded to the edge HD map server in the background through the edge web server.

4) The edge HD server responds to the request made by the vehicle and returns massive HD map data and provides instant service to the vehicle through the edge web server. At this time, the vehicle downloads HD map data from the edge HD map server in the edge computing node. Although the amount of data is numerous, the negligible transmission and propagation delay can make the service to vehicle more fast, reliable, and high-quality.

During the automatic driving process of the vehicle, the edge HD map server always obtains the geographical position of the vehicle through the HD positioning module of the vehicle. The vehicle sends a request to the cloud web server when the vehicle is about to exit the coverage of the edge HD map server and needs to download HD map data in the new area. The request contains the location and speed of the vehicle. The cloud web server will figure out the edge HD map server which the vehicle is about to enter according to the request. Then, the it returns the next-edge HD map server's IP address to the vehicle and inform the vehicle's IP address to the next-edge HD map server. In this way, the vehicle accesses the next-edge HD map server through the newly IP address obtained while it is driving normally within the coverage of the original edge HD map server.

3.6. HD Map Correction

Each edge computing node has its corresponding number and IP address, and the cloud server delivers the HD map data to edge computing nodes according to their geographical location. At the same time, when the sensor of autonomous vehicle detects that the road data in the field is incompatible with the edge server, the autonomous vehicle will still be guided according to the road data in the field, and the suspected incompatible road data will be transmitted back to the edge HD map server cluster in the edge computing node. For example, if a road arrives at the end, but the data in the HD map server is not updated in time, which will guide the autonomous vehicle keep driving. However, after the on-board sensor obtains the road condition, it will decide to terminate driving. The general process is shown in Fig. 11.

3) The vehicle returns the incompatible road information to the edge HD server. If the data affects driving safety (such as road condition, driving lane selection, etc.), the edge HD server records the incompatible information of the point.

4) The edge HD map server returns the command to the vehicle, so that the vehicle performs automatic driving according to real-time road data captured by on-board sensors such as HD radars, HD cameras, and the like. These data will be analyzed by the vehicle artificial intelligence terminal to guide the automatic driving of the vehicle at the position.

5) When more than 50% autonomous vehicles that have passed the area of latitude and longitude upload the same incompatible information to the edge HD map server, edge HD map server will upload the information to the cloud HD map server through the network and request to modify the HD map data of the area.

6) The cloud HD map server modifies the data in the local database and returns a message allowing to the modification to the edge HD map server, after which the edge computing node provides the service to the vehicles according to the modified data.

In such scenarios, the MEC provides the ability to store HD maps, the ability to dynamically update maps, and provide the ability to interact with the central cloud. After the network deploys the MEC and the corresponding functional services, the vehicle can utilize the corresponding communication modules to obtain such application service, and the map data can be updated by uploading information detected by vehicles' on-board sensors.

4. Experiment and Result Analysis

This paper has carried out two kinds of experiments to verify the superiority of the “cloud-edge-end” mode. Path planning testing compares the preparation time of path planning with HD maps in “cloud-end” mode and “cloud-edge-end” mode, and verifies that autonomous vehicles with edge computing framework can cache HD map data faster to complete path planning and navigation more quickly. The HD map data correction test compares the time required for the HD map data being corrected and deployed to end (that is, the autonomous vehicles) in “cloud-end” mode and “cloud-edge-end” mode.

4.1. Experimental Environment

The application of the “cloud-end” HD map mode is composed of one PC as the client, which is written in JavaScript to simulate the autonomous vehicle; Two Ngnix servers deployed on Alibaba Cloud are used as cloud web servers and cloud HD map servers respectively. The hardware configuration is: Linux operating system, 8G RAM, Intel Xeon (Cascade Lake) Platinum 8269CY processor; The data is managed by the MySQL database, and the client to the cloud web server needs to go through 14 hops route. In the "cloud-edge-end" mode, two edge HD map servers in the edge node form a cluster. The edge nodes of cluster deployment are managed by the cloud agent under the framework provided by KubeEdge, and the edge HD map server is configured in the Docker container. The client to edge nodes needs to go through 1 hop route.

The test data is consisted of 4 pieces of HD map tiles with whose Gaussian projection coordinates are {X=720640, Y=473344}, {X=720640, Y=473088}, {X=720896, Y=473088}, {X=720896, Y=473344}. They are named as Tile1,2,3, and 4 respectively. In the "cloud-end" mode, the autonomous vehicle needs to cache all 4 map data at the same time. In the "cloud-edge-end" mode, only one of the map data needs to be cached

4.2. Analysis of Experimental Results

Electronic map navigation generally requires more than 10 levels (L10) of tile data. The higher the level of the tile, the clearer it will be. The HD map requires at least L20 tiles in order to achieve "lane-level" navigation. Fig. 12 shows the tile layered data size for this experiment. Since the initial data required for path planning of autonomous vehicle is different between "cloud-end" mode and "cloud-edge-end" mode, the autonomous vehicle in "cloud-end" mode needs to download 4 pieces of tile data at a time; The autonomous vehicle in "cloud-edge-end" mode, only needs to cache one HD map tile data of the geographical location where it is. What`s more, the route distance is reduced by more than 10 hops in the network distance, which contributes to the faster download of the map data and the shorter time for completing the path planning preparation. Fig. 13 is a comparison of time results.

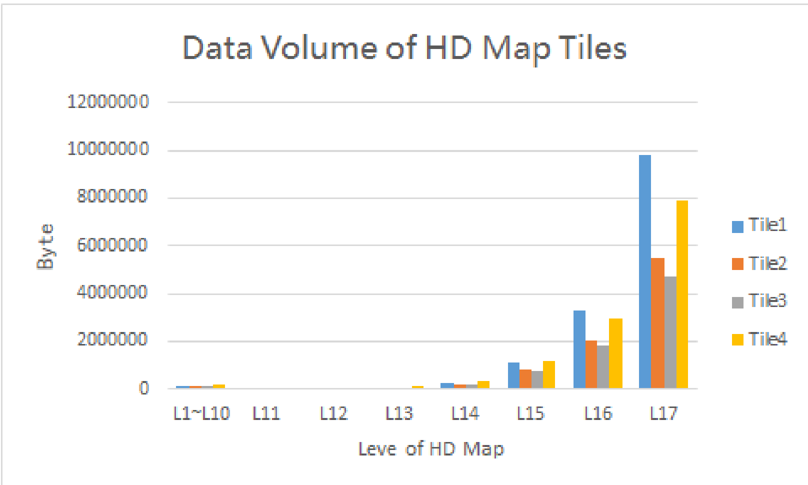

Fig. 12. Comparison of HD map data for experiments.

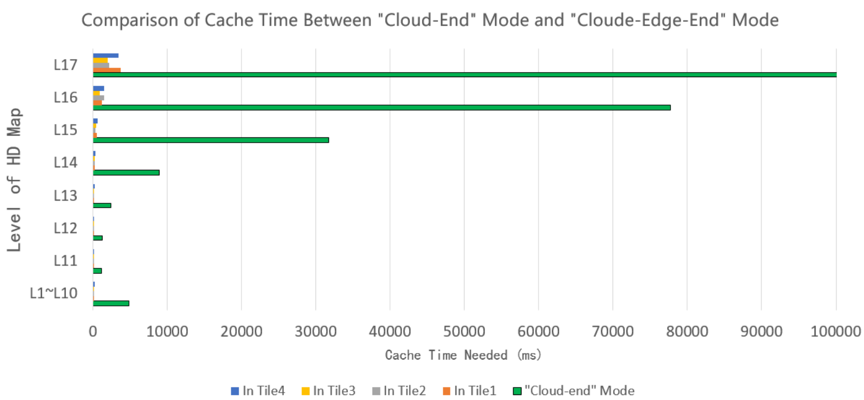

Fig. 13. Comparison of cache time between "cloud-end" mode and "cloud-edge-end" mode.

When the HD map data is inconsistent with the field data, the system will start the data correction process based on the information collected by the on-board sensors of the autonomous vehicles. Assume that the road with error is located in one of the layer of Tile 1, 2, 3 and 4, and the data amount of the layer is X, the transmission rate of the router is $V_{transmit}$, and the processing delay is ignored.

In “cloud-end” mode, the network distance is N-hop routing, and the amount of uploaded data is Y, the time T_1 from discovery to error reporting and correction is

$$({}^{Y}/_{V_{transmit}}) \times N;$$

The time T_2 taken to update the on-board map after correction is

$$({}^{Y}/_{V_{transmit}}) \times N;$$

Total time will be T_1+T_2.

In the “cloud-edge-end” mode, the network distance is 1-hop routing, the amount of uploaded data is X, the physical distance between the autonomous vehicle and the HD edge server could be ignored, and the processing delay could be ignored, too.

Time T_1 to correct map with uploading data to edge HD map server is

$$({}^{X}/_{V_{transmit}});$$

Time T_2 to upload data from edge HD map server to cloud HD server is

$$({}^{X}/_{V_{transmit}});$$

Time T_3 to delivery data back to edge and update the on-board map is

$$({}^{Z}/_{V_{transmit}}) \times N + ({}^{X}/_{V_{transmit}});$$

(Z is acknowledge message of map updating, since the corrected map has been stored in edge HD map server, autonomous vehicles can download the corrected HD map as long as the cloud permits.)

Total time will be $T_1 + T_2 + T_3$.

Fig. 14 shows the time taken to calibrate the HD map data in two modes, which can verify that the “cloud-edge-end” mode can calibrate and redeploy the HD map to the autonomous vehicle faster.

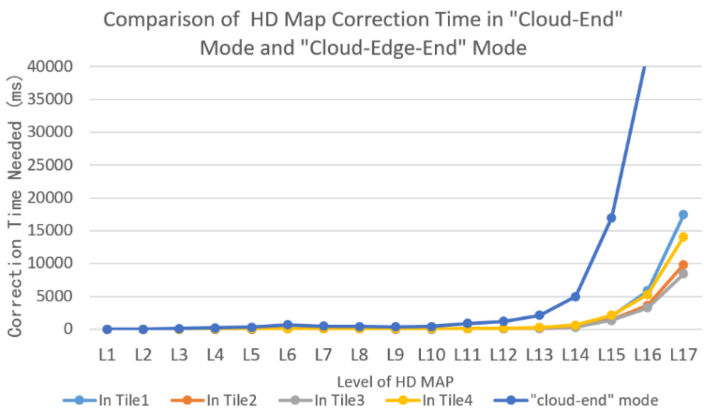

Fig. 14. Comparison of HD map correction time in “cloud-end” mode and “cloud-edge-end” mode.

5. Conclusion and Future Work

This paper proposes a MEC system framework for HD map applications, and introduces its application mode, system framework design and implementation, including system architecture, functional modules, HD map data distribution workflow and communication process between the autonomous vehicle client and the sever. Moreover, we have worked out the performance testing, analysis and comparison. The result shows that the MEC system framework for HD map applications can provide accurate map services for autonomous vehicles with strong scalability and stability. The next research direction should focus on the HD map update mechanism, overcoming the difficulties of real-time update and data synchronization. At the same time, the method in releasing the load of HD map server by communication between autonomous vehicles(V2V) should be explored, which will be significant in assisting automatic driving.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Rongbo Zhang proposed a main structure of this paper, and the experiments had been carried out by him; Kaiyu Cai gives guidance throughout the process of writing, and gives many practical suggestions in the direction of research.

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