Research on Cooperative Vehicle-Infrastructure System Use Case Based on Edge Computing Technology

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Abstract. The ability of edge computing determines the effectiveness of the cooperative vehicle-infrastructure system to improve traffic safety, efficiency and capacity, enabling traditional information release method have backstage processing and distribution. It is converted to vehicle, road and backstage after being processed by edge computing algorithm. Vehicles are timely and effectively controlled and induced. Based on the full analysis of the development status at home and abroad and the analysis of actual engineering needs, this paper proposes the composition of the cooperative vehicle-infrastructure system and the main factors affecting edge computing, studies the existing edge computing methods, and finally combines the current smart highway demonstration projects. The actual needs put forward the cooperative vehicle-infrastructure use case research based on edge computing. The use case analysis has significant guiding role for the design, R&D and engineering implementation of the smart highway cooperative vehicle-infrastructure system in China.

1. Introduction

With the vigorous development of “Internet Plus”, “Big Data”, “Cloud Computing” and other technologies, as well as the gradual deepening of the implementation of the "13th Five-Year Plan" and supply-side reforms, China’s intelligent transportation has entered a new development period. The core of intelligent transportation is to continuously change the traffic behavior and the form of transportation organization, to make the transportation system well organized and solve the problems of traffic safety, congestion and environment pollution. In this context, cooperative vehicle-infrastructure technology is favored at home and abroad due to its unique advantages in improving traffic safety and capacity. At the same time, China’s Ministry of Transport organized a new generation of traffic control network and smart highway pilot projects, clearly taking “road-transport integrated vehicle-infrastructure coordination” as an important pilot direction [1], and the industry is actively promoting cooperative vehicle-infrastructure for smart highways system construction to implement the requirements of the “Outline of building China’s strength in transportation network” [2]. As the advanced stage of Intelligent Transportation Systems (ITS), cooperative vehicle-infrastructure system (CVIS) deals with advanced wireless communication and new generation of Internet technologies to comprehensively implements real-time dynamic information interaction between vehicles and roads. It carries out active vehicle safety control and road collaborative management on the basis of full-time dynamic information collection and integration. It fully realizes the effective coordination of roads and vehicles, ensuring traffic safety, improving traffic efficiency, and forming environment friendly roads traffic system. In addition to vehicle-infrastructure communication technology, edge computing is the core algorithm of CVIS system. This section provides an overview of the worldwide development in CVIS and introduce the multi-
access edge computing technology (MEC). In context of the similar concept, cooperative vehicle-infrastructure system (CVIS), V2X and V2I can be considered as the same in this paper.

1.1. Overview of the Worldwide Development in CVIS
This subsection presents an overview of the cooperative vehicle-infrastructure system (CVIS) worldwide development in the US, Europe, Japan and China. Among them, the United States has carried out research on transportation, vehicle safety, vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I) communication, vehicle perception and other related project research [3][4]. The technology in the US is relatively mature. The accusations of connected car, autonomous vehicle, intelligent connected car systems were early in the US, and the government built a platform based on policy guidelines, federal/state laws and regulations, and planned to focus on DSRC [5][6][7]. Research in Europe is a bit later than in the United States, but many achievements have been made in the areas of system architecture and communication standards [8]. Europe started early in the research and development of intelligent connected car systems, attaches importance to top-level design and new technology research and development, and has guided innovation projects through funds in key areas. A considerable part of the research results has been put into application. Europe remains relatively neutral on basic technology selections [9][10]. Japan began researching intelligent traffic management technologies to ensure traffic safety and smoothness in the late 1990s. Led by the government, auto manufacturers have assisted in developing the corresponding connected car systems. China's cooperative vehicle-infrastructure work started relatively late, but the catch-up effort and the government's implementation efficiency is high. There are various parts actively cooperate and the landing is expected to approach. A number of national test sites for connected and self-driving cars are established which aim to facilitate R&D, standard studies and policy formulation, as well as to test and certify connected car technologies. There are several established research centers, related to automated driving, for bilateral collaboration between Chinese and European OEMs, authorities and universities in China and in Europe.

1.2. MEC Terminology, Framework and Use Case
According to [11], Table 1 summaries some glossary terms relating to the conceptual, architectural and functional elements within the scope of work on Multi-access Edge Computing.

| Multi-access Edge Computing (MEC) | System which provides an IT service environment and cloud-computing capabilities at the edge of an access network which contains one or more type of access technology, and in close proximity to its users. |
|----------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| MEC application                  | Application that can be instantiated on a MEC host within the MEC system and can potentially provide or consume MEC services. |
| MEC host                         | Entity that contains a MEC platform and a virtualisation infrastructure which provides compute, storage and network resources to MEC applications. |
| MEC platform                     | Collection of functionality that is required to run MEC applications on a specific MEC host virtualisation infrastructure and to enable them to provide and consume MEC services, and that can provide itself a number of MEC services. |
| MEC service                      | Service provided via the MEC platform either by the MEC platform itself or by a MEC application. |
| MEC system                       | Collection of MEC hosts and MEC management necessary to run MEC applications. |

According to [12], Multi-access Edge Computing enables the implementation of MEC applications as software-only entities that run on top of a virtualization infrastructure, which is located in or close to the network edge. The Multi-access Edge Computing framework shows the general entities involved. These can be grouped into system level, host level and network level entities.
Figure 1 illustrates the framework for Multi-access Edge Computing consisting of the following entities:

- MEC host, including the following:
  - MEC platform;
  - MEC applications;
  - Virtualization infrastructure;
- MEC system level management;
- MEC host level management;
- External related entities, i.e. network level entities.

According to [13], MEC makes it possible for service localization and short-distance deployment to better support high-bandwidth and low-latency services. Meanwhile, the CVIS has strict requirements on low-latency, which is one of the typical application scenarios of MEC. MEC can realize the offloading and processing of computing tasks such as traffic situation recognition and vehicle-mounted applications to the edge server, and provide the necessary computing resources for applications such as accident warning, assisted driving, route optimization, and intelligent information guidance. Applying mobile edge storage to Internet of Vehicles communication, a large amount of information such as traffic conditions, driving guidance, and hotspot information can be pre-cached in the roadside system to provide low-latency content delivery services for smart vehicles traveling on the road.

2. Architecture of the Cooperative Vehicle-infrastructure Control System

The cooperative vehicle-infrastructure system is composed of roadside intelligent stations and the cooperative vehicle-infrastructure management and control module. It uses edge computing (road-side computing) as the core technology and accesses localization perceived data, business platform data, through DSRC, LTE-V, 4G, industrial Ethernet and other communication methods. The CVIS system is supplemented with high-definition maps and high-precision positioning environments, real-time computing and analysis of local-level traffic operation conditions, traffic incidents and situations, to realize the generation, processing and release of refined roadside traffic control strategies. Figure 2 illustrates the Architecture of the CVIS.
2.1. Roadside Intelligent Station
The roadside intelligent station has powerful edge computing capabilities and traffic status analysis capabilities, supports the access of multiple roadside sensing devices, supports real-time interaction between vehicle and road information. It can achieve data fusion of multiple traffic sensing devices, coordinated management and control strategy generation and information distribution applications. The roadside intelligent station is composed of roadside unit (RSU) and edge computing nodes.

The roadside unit (RSU) realizes the information interaction between the road-side infrastructures and the vehicles. The road-side unit can broadcast the basic information of the road network, traffic control information, and traffic incident information to the vehicles, and at the same time can collect vehicle speed, trajectory and other information through the on-board unit (OBU). The RSU provides an open hardware platform and is compatible with multiple communication methods, including DSRC, LTE-V, 5G, and so on. At the same time, RSU can be equipped with 4G modules to achieve communication transmission under cellular networks.

Edge computing nodes mainly perform localized information access processing and publishing. Edge computing nodes have the ability to access real-time monitoring data, high-precision positioning data, and access to traffic incidents and monitoring of the CVIS system. Edge computing nodes enable realizing the forwarding of V2X application data, integrating analysis of roadside sensor monitoring data and OBU vehicle real-time data, generating roadside level control strategies, realizing centre-level and roadside-level traffic control strategy information, and realizing online distribution and information interaction with OBU.

2.2. On-Board Unit
Cooperative vehicle-infrastructure based on the national traffic control network requires an intelligent on-board unit (OBU) system that provides vehicle operation-related information to the roadside edge computing nodes and back-end systems, and receives control instructions from the CVIS. The OBU system can receive the surrounding road condition information, real-time status data of surrounding vehicles, analyze and calculate the real-time traffic status, and upload the collected information through the RSU. The OBU supports CAN BUS data transparent transmission, and the vehicle's working condition information (including total mileage, current mileage, remaining fuel in the fuel tank, engine speed, vehicle speed, frame number, vehicle battery voltage, etc.). The speed information (including rapid acceleration, sudden braking, sharp cornering, and accidental collision) is sent to the OBU. The OBU system can transmit the vehicle's own status data to the RSU and control center. OBU has cooperative driving guidance and control service information display and broadcast function, supports voice interaction. OBU should reserve an interface for future autonomous vehicle tests.

3. Use Case Analysis
The cooperative vehicle-infrastructure system use cases are organized in two main categories. First, the lane-by-lane network control category, based on the acquisition of vehicle position at the lane level, it provides low-latency, highly reliable lane-level information services and guidance to vehicles through edge computing nodes, and realizes the initial data loading of high-definition map. It can be divided into three cases, bottleneck collision warning case, service area information and merge reminder case and tunnel event warning case. Second, the customized management and service category can be divided into two cases, lane-level event reminder and speed alert case and adverse weather warning and safety services case. The following subsections describe four cases in detail.

3.1. Bottleneck Collision Warning
In the bottleneck collision warning case, the cooperative vehicle-infrastructure system has such features: First, merge reminder. The edge computing node obtains the speed and position information of the vehicles on the ramp adjacent to the emergency lane and the vehicles on the ramp through OBU, millimeter wave radar and the background video event detection information. The vehicle status information is used to judge whether there is a risk of collision between the offending vehicle and the on-ramp vehicle, and remind the vehicle to slow down or drive carefully. Second, reminder of vehicle violation information. Detecting offending vehicles through OBU, millimeter wave radar, and
background video event detection information, issuing early warning information to offending vehicles, and issuing collision risk early warning to surrounding vehicles. The intelligent roadside station obtains vehicle position information through OBU and millimeter wave radar on the roadside, and obtains event information such as vehicle violations and emergency lane occupation through the event detection subsystem. After edge computing process, it forms a release strategy on the front end and issues early warning to different vehicles information. Figure 3 illustrates the bottleneck collision warning use case.

![Figure 3. Bottleneck collision warning.](image)

### 3.2. Tunnel Fire Alert

Compared with open highway scenario, the tunnel has the characteristics of poor visibility and narrow space. Once a traffic accident or special situation occurs, it is extremely difficult to handle and rescue. The CVIS is used to notify the accidents that will enter the tunnel and in the tunnel. Event information enables vehicles to make advance judgments, induce vehicles to change their driving behavior, and reduce accidents in tunnels.

![Figure 4. Tunnel fire alert.](image)

In tunnel fire alert case, smoke, temperature, and CO in the tunnel will be detected as abnormal conditions. The strategy development and release module calculates real-time displacement data of vehicles connected to the RSU, and simultaneously accesses video monitoring events and tunnel fire reporting system events. It performs fusion analysis and calculation of fire warning information to form different release strategies to related vehicles it can be issued with. Warnings can be issued to related vehicles through VMS and tunnel FM radio. Vehicles with OBU directly obtain the prompt information through the RSU. Non-OBU vehicles obtain information prompts through the background system. The CVIS control software sends content to the information service system, and the information service system issues information to vehicles through VMS, FM radio, and third-party information distribution systems.

### 3.3. Lane-level Event Reminder and Speed Alert

In this case, the vehicle is driving on the demonstration road when a traffic incident occurs or the traffic volume is large, according to the occupied lane event or the affected area, the RSU will issue a warning of traffic incident, lane speed limit, changing lane prompting and other strategies to the vehicles. At the same time, the speed limit value or lane traffic status is pushed to the OBU vehicle or posted to the
roadside variable message signboard (VMS) for reminding. First, work zone information warning. The platform obtains the maintenance event type, pile number, start time, end time and other information from the construction maintenance reporting system. Second, forward accident warning. The application system accessed real-time traffic accident information in an interface manner, including the location, scope, and type of accidents. The application system can be used as an information service platform or a video event detection platform. Third, lane-by-lane management and control. The background data access mainly acquires vehicle position data and speed data in real time, and periodically acquires information such as perceptual access video monitoring events and reporting system events. The event information mainly includes the event type, event name, lane occupied, event description and highway route code.

The RSU interacts with the OBU vehicle in real time to obtain vehicle position and speed data, and push policy information to the vehicle. RSU interacts with the CVIS management and control module in real time for data interaction, and implements the interaction and access of map data on the demonstration road. RSU access the traffic accident information from the video event detection platform and event reporting system in real time. The CVIS management and control module is connected with the information service system to release information through VMS. Figure 5 illustrates the lane-level event reminder and speed alert use case.

3.4. Warning of Vehicle Track Deviation in Foggy Weather

In a foggy weather condition case, obtaining meteorological station information from edge computing nodes or from background systems, and issuing meteorological information based on vehicle location.

In a foggy weather condition case, the vehicle's OBU is used to obtain the vehicle's position information in real time, determine the vehicle's driving trajectory, and determine the relative position of the vehicle with the OBU. When a vehicle crosses a double solid line or a single solid line during driving, the RSU alerts the driver through the OBU. If adjacent vehicles are too close, OBU issues warning information to the driver of the vehicle. The RSU obtains vehicle position information through OBU on the roadside, determines the relative position and driving trajectory by edge computing, forms a release strategy for related vehicles, and issues early warning information to relevant vehicles.

4. Conclusion

To conclude, this paper analyses various cooperative vehicle-infrastructure system use cases based on edge computing technology. First, it introduces the background and benefits of the cooperative vehicle-infrastructure system as a new trend of intelligent transportation systems. Then it provides an overview of worldwide development in the CVIS, which includes the US, Europe, Japan and China. Next, it introduces the terminology, framework and use cases in Multi-access Edge Computing. Based on MEC, section 2 provides an architecture of the cooperative vehicle-infrastructure control system and its key components. The ability of edge computing determines the effectiveness of the cooperative vehicle-infrastructure system to increase the safety, efficiency and convenience of the transportation system. In the final and the most important section, this paper analyses the cooperative vehicle-infrastructure system use cases, such as bottleneck collision warning case, tunnel fire alert case, lane-level event
reminder and speed alert case, and abnormal weather condition case. Based on the edge computing technology, the use case analysis has significant guiding role for the design, R&D and engineering implementation of the smart highway cooperative vehicle-infrastructure system in China.

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