Research on Vehicle-to-Road Collaboration and End-to-End Collaboration for Multimedia Services in the Internet of Vehicles

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ABSTRACT With the development of mature communication network technologies such as 5G, edge computing and slicing, business applications in areas such as telematics and intelligent transportation need the support of vehicle-road collaboration technologies. Due to the mobility of vehicles and the heterogeneity of communication interfaces, there are many challenges for data transmission and the processing of telematics. Therefore, network resources, roadside unit devices and sunken edge nodes need to work together to guarantee real-time network communication. Thus, they can jointly help improve the quality of network services and user experience and show the level of vehicle-road collaboration in terms of safety, efficiency and service. In view of future 5G network-related technologies and C-V2X development trends, this paper provides a comprehensive technical solution framework for telematics based on end-edge collaboration, and combines network resource deployment optimization and edge caching technologies for video transmission tasks in telematics application scenarios. By adding both a 5G base roadside unit (RSU) station and an UAV mobile base station, network resources are better allocated for scalable coded video, and a relatively better edge caching strategy is obtained based on user mobility analysis. Aiming to improve the network system performance, the vehicle side, roadside and edge side are jointly considered to improve the utilization efficiency of limited network resources. In this paper, we hope to provide a practical and effective service architecture for telematics video application scenarios through a convergence scheme of network resource allocation and edge caching configuration.

INDEX TERMS Internet of vehicles, multimedia video, 5G, vehicle-road collaboration.

I. INTRODUCTION
A. BACKGROUND
Cars and modern life have become inseparable; cars are not only simple tools for transportation but can also be seen as moveable “homes” for ordinary people. With the continuous upgrading and optimization of the automotive industry, the rapid development of communication technology and the popularization of road intelligence, intelligent transportation systems have become a strategic direction for the development of the national transportation technology sector. Among the intelligent systems, the high bandwidth of the 5G network can provide reliable guarantees for end-to-end video transmission and real-time interconnection. Smart driving technology continues to make new progress, and connected vehicle technology is representative of the new round of transportation technology trends. The mainstream industry unanimously expects that it will be a general trend to upgrade the traditional automobile industry to an intelligent networked automobile industry, and that the new generation of intelligent transportation systems will develop in an intelligent, networking and collaborative way. Network connectivity is the basis of vehicle-road coordination, which needs to support the interaction and sharing of information between human-vehicle, vehicle-vehicle, vehicle-road and vehicle networks in real time and provide data communication to support cooperative decision-making and control. Most of the various application scenarios of vehicle-road collaboration require video-based multisourced data fusion. Efficient analysis and prediction of the road’s surrounding environment can be performed to achieve optimal resource allocation decisions. With the deployment of 5G, slicing and edge computing, the development of a “human-vehicle-road-edge-cloud” will be truly collaborative. Since the development of technology...
needs time to settle, from the current industrial and academic situations, the future shows a mixed state of networked and nonnetworked vehicles for some time. It is expected that the framework and system of the overall vehicle-road collaboration system for all scenarios will gradually mature in the process of development [1], [2].

In the process of vehicle-road cooperation evolution, intelligent networked traffic management needs to play its respective role through components such as roadside units (RSU), edge computing units, intelligent traffic signals, roadside sensors, etc. RSUs are responsible for decision-making and data broadcasting; edge computing units are responsible for auxiliary computing and data collection fusion; roadside sensors consist of HD camera, LIDAR, millimeter wave radar, and are where video information can be the most intuitive and the most real-time detection of the location and speed of vehicles and pedestrians within the view range, statistics of real-time traffic flow on the road, etc., can be detected. Co-awareness is a perceptual computing framework that achieves accurate and comprehensive knowledge of the research object by pooling and collaboratively analyzing sensing data from different sensing units. An intelligent networked traffic management system can collect various traffic participant information detected by sensors (e.g., pedestrian status at intersections, nonmotorized vehicle status, road status, passing vehicle status, traffic flow, etc.), as well as obtain data from other RSUs and the management center cloud platform. The RSU then sends the current intersection status to the passing vehicles and pedestrians with a fixed communication protocol and data interaction standard [3], [4].

Faced with the increasing demand for multimedia in-vehicle content and the consequent huge data volume, it is necessary to consider how to improve network performance and user experience with a limited number of available network resources. Therefore, based on the analysis of the telematics business scenarios and related technical background, this paper describes the design of an end-edge collaboration-based telematics platform framework that combines network resource deployment optimization and edge caching techniques to propose a possible technical solution for telematics application scenarios oriented to numerous video tasks. For video-related tasks, scalable video coding techniques are introduced into wireless video multicast. Using scalable video coding (SVC) techniques, the video is divided into a base layer and multiple enhancement layers. In the face of different network channel environments in practical application scenarios, users can selectively receive the video enhancement layer. Users with good channel conditions can receive the base layer and more enhancement layers [5]. To better guarantee the video quality and allocate resources reasonably and efficiently in the telematics scenario, this paper considers reducing the pressure for macro base stations by increasing the joint work of RSU 5G base stations and UAV mobile base stations. An optimized edge caching strategy in the telematics environment is also considered to balance the core network backhaul burden. By analyzing the roadside RSU connection and vehicle mobility, the amount of data downloaded by vehicle users is optimized [6]. In summary, this paper hopes to provide a practical and effective service architecture for telematics video application scenarios through a convergence scheme of network resource allocation and edge cache configuration.

B. DOMESTIC AND INTERNATIONAL RESEARCH

In terms of drones as temporary small base stations, Kang [7] proposes a cluster-based unmanned aerial vehicle (UAV) deployment scheme with a long- and short-term memory (LSTM) based caching scheme to cache popular multimedia content. Chen et al. [8] also mentions the use of drones as an important complement to ground-based D2D caching nodes to assist in dynamic trajectory involvement. In addition, the application area of using UAV-assisted fog computing systems has been studied [9], Jiang et al. [10] aims to maximize the throughput between Internet of Things (IoT) devices in the IoT by enabling cached drones to pass through the placement of content caches and drone locations. Mei et al. [11] investigates a UAV mobile edge network for information physical systems (CPS) that provides communication and mobile edge computing (MEC) services to ground terminals via fixed- or rotary-wing UAVs.

For edge caching, some scholars have proposed a scheme using different physical and time scales at the application and have developed a dynamic caching algorithm to obtain video quality adaption, cache placement, and radio bandwidth allocation decisions [12]. Some scholars also consider the performance of various DASH adaptive algorithms on in-vehicle networks; it can be found that different algorithms have advantages and disadvantages in providing in-vehicle multimedia content services [13]. Feng et al. [14] proposes a joint cache allocation and multicast delivery scheme for reactive systems delivering video on demand and develops a joint design of the cache bandwidth allocation algorithm and delivery mechanism for active systems playing video periodically. Jiao et al. [5] investigates dynamic resource allocation for scalable video streams over cache-enabled wireless networks with time-varying channel conditions and proposes a dynamic cache and resource allocation (DCRA) algorithm. Fang et al. [15] proposes a stochastic network algorithm (SNC) based approach to obtain upper bounds on the random playback latency of an in-vehicle video content delivery network with cache-enabled RSUs.

II. RELATED WORKS

With mobile internet communication, C-V2X empowers ubiquitous connectivity for cars. It helps automobiles achieve connectivity with people, roads, cloud-based service platforms and fellow vehicles. Through the rapid development of infrastructure in intelligent transportation systems, single-vehicle intelligence is evolving into multivehicle intelligence. In the future, multivehicle intelligence will evolve into more complex vehicle-road hybrid intelligence. In the end, edge and cloud platforms will be mutually integrated and
empowered to form a more ubiquitous hybrid intelligence group. A new generation of information technology, including slicing and AI, will serve as a technical base to help realize intelligent decision-making and collaborative control. The ultimate goal is to build a safe and efficient intelligent transportation and smart city.

In the current stage, we need to focus on a 4G/5G/C-V2X collaborative intelligent network for the development of vehicle-road cooperative networks. The wireless side supports super uplink to realize high-speed service download for vehicle-road cooperation. For C-V2X, LTE-V and 5G NR V2X, collaborative networking has been realized. Core network side MEC completes local data processing, encryption and decision-making for multiple data sources, providing real-time and highly reliable communication capability. Providing differentiated services through slicing technology to meet the needs of different vehicle-road cooperation services.

A. C-V2X-BASED VEHICLE-ROAD COLLABORATION

1) INTER-VEHICLE NETWORK AND COMMUNICATION INTERFACE

In the era of 5G, automotive networking is not only helped by mobile networks, but also by industry communication specifications, which are equally important. C-V2X is an important standard. An intervehicular network (also known as a vehicular ad hoc network (VANET))) is an open mobile self-organizing network with vehicles, roadside units and pedestrians as nodes in the traffic environment. It provides high-speed data access service for vehicles in a state of high-speed movement to realize the information interaction between V2X.

V2X technology has two main routes: DSRC and C-V2X. DSRC is a V2 V and V2I communication protocol based on IEEE802.11. Wi-Fi technology improved the development of the IEEE 802.11p standard and IEEE 609 standard. This technology provides short-range wireless transmission to guarantee real-time image, voice and data information transmission and ensures low latency, low interference in the communication link and system reliability.

C-V2X vehicle wireless communication technology is based on 3G/4G/5G and other cellular network communication technology evolution formations. The LTE-V2X system equipment consists of user equipment (UE), RSUs, and base stations.

According to the 3GPP standard, C-V2X contains two kinds of communication interfaces: the short-range direct communication interface between vehicles, people and the road (PC 5, point-to-point direct communication), and the communication interface between the terminal and base stations (Uu, direct communication between device and base station). When a C-V2X-enabled terminal device is within the coverage area of a cellular network, the Uu interface can be used under the control of the cellular network. Examples are oriented to vehicle terminals, smartphones, roadside units, smart devices in intelligent transportation systems, etc.

The PC 5 interface provides direct communication similar to D2D. Regardless of whether it is in the coverage area of the cellular network, terminal devices supporting C-V2X can use the PC 5 interface for V2X communication. C-V2X combines the PC 5 interface with the Uu interface to support V2X services.

5G-V2X will support more diverse scenarios and integrate multiple wireless access methods. V2X based on 5G new airports can provide high throughput, wideband carrier support, ultralow latency and high reliability, thus supporting numerous autonomous driving-oriented technology requirements. Adding scenarios such as vehicle formation, sensor extension, and advanced driving.

2) THE IMPORTANT ROLE OF RSUs IN VEHICLE-ROAD COOPERATION

A RSU is one of the key devices for vehicle-road collaboration and is an indispensable core unit for conducting C-V2X telematics services. It is deployed on the roadside, and connects roadside infrastructure, sensors and vehicles. It collects and sends information on roadside infrastructure, sensors, traffic participants, high-precision dynamic maps, vehicles, etc.

The RSU acquires intersection vehicle data through V2X communication based on vehicle-road cooperation technology. Thus, it supports traffic intersection lane-level data statistics as well as modeling analysis. It can provide information assistance for traffic management departments to develop traffic flow analysis and schedule plans. On the one hand, the roadside unit determines the safe speed of vehicle passage by analyzing and predicting the vehicle trajectory and broadcasts it to vehicles through V2I communication; on the other hand, it adaptively controls the passage phase and signal timing at the next moment based on the current statistical traffic volume of each lane. The OBU is responsible for sending its own data to the RSU through V2I communication and realizing information interaction between vehicles, as well as undertaking the function of receiving real-time broadcast messages from the roadside.

As an important application area of 5G, the construction of 5G networks and C-V2X networks will be divided into 3 phases. The first phase is the hybrid network phase, in which the 5G network and C-V2X network are independently networked, and the base station and roadside unit (RSU) are connected to each other by wired or wireless means. The second phase is the cooperative networking phase, which is also the current phase, where the 5G network and C-V2X network will gradually converge, and the base station and RSU will gradually be upgraded to one device that supports both 5G and C-V2X networks. The third stage will reach the converged networking stage. One device and one set of networks will be able to realize all the functions of 5G and C-V2X. According to the definition of 3GPP, RSUs are divided into two types: terminal-type RSUs and base station-type RSUs. Terminal type RSUs are mature and have been...
deployed and applied in many places, while base station type RSU equipment is still in the developmental research stage.

![Collaborative networking stage](attachment:image1)

![Collaborative networking stage](attachment:image2)

**FIGURE 1.** The evolution of the internet of vehicles off the road network.

**B. NETWORK RESOURCE DEPLOYMENT SOLUTION OPTIMIZATION**

The development of smart traffic and high-definition cameras has triggered a rapid growth of video traffic. The large amount of video data undoubtedly intensifies the pressure on wireless network resources. To meet the video quality needs of different users, there are options to introduce multicast technology as well as SVC technology. These two approaches help improve the effective utilization of network resources. However, there are also other ways to help reduce the pressure on macro base stations.

5G base stations are the core equipment of 5G wireless networks. Macro base stations are mainly used in outdoor wide coverage scenarios. They carry a large number of users and have high transmit power. Micro base stations are usually used for indoor scenarios, outdoor coverage blind areas, outdoor hotspots and other areas to compensate for blindness and heat. Macro base stations are much less flexible than micro base stations because they require separate server rooms. To relieve the pressure of macro base stations (MBSs), small fixed base stations can be introduced in heterogeneous cellular networks. With the help of social tower resources, 5G base stations can be deployed for blind and hot patching, thus enhancing network coverage. We propose to consider adding the RSU function to 5G base stations with the RSU function. This operation can help save deployment and installation costs and reduce latency.

![AAU](attachment:image3)

**FIGURE 2.** The integrated RSU base station.

**FIGURE 3.** The distributed base station type RSU structure.

Creating 5G base station-based RSUs in this way will help the development of application scenarios for the telematics business in many ways. First, it realizes the enhanced coverage of the 5G network to meet the demand for upstream and downstream bandwidth of telematics services such as vehicle-road collaboration and autonomous driving. Second, a large amount of telematics business data, which traditionally relies on Uu transmission, can be broadcast to the outside world through PC5 direct connection communication, reducing the occupation of 5G network resources. Third, it realizes...
the common site deployment and unified deployment and operation and maintenance of 5G base stations and RSUs. Sharing transmission, power supply, communication cables and other infrastructure is conducive to resource saving and sharing and effectively reduces the deployment cost of base stations and RSUs. In the current research, there are mainly two different forms of base station type RSUs to suit different application requirements. One is the integrated and integrated form, and the other is the distributed form. Among them, the distributed form integrates the PC5 RF and antenna in AAU, and PC5 and 5G NR share the processing unit of the baseband. It can also be found from the system architecture diagram that the distributed form is more cost effective.

On the other hand, the deployment of microstations relies on the prediction of the long-term spatial and temporal distribution of communication usage. In the face of the highly mobile telematics scenario, it can be supplemented with other network deployment schemes to secure a large amount of data communication needs, such as video information. In the literature, use of UAV base stations to enhance the efficiency of wireless networks is proposed. Since communication shadows are inevitable in cities, extreme weather can also bring the possibility of damage to communication infrastructure. In this case, UAVs can be chosen to provide wireless communication support [16], [17]. Compared to traditional small fixed base stations, UAV mobile base stations can be deployed faster and with a reduced cost. With the high mobility and low cost consumption of UAVs, it is of research interest to have UAVs carry edge devices with computing service capabilities to assist ground vehicle terminals in obtaining appropriate access and computing services [18], [19].

Therefore, this paper decides to fuse the advantages of both 5G base station type RSU and UAV mobile base station solutions into a framework structure by working together to effectively support the communication needs of application scenarios in telematics that require a large data backhaul and a large amount of repetitive data downlink per unit time. Based on SVC coding, the streaming video resources are partitioned into multiple layers, with the base layer provided by an RSU-capable macro base station to the multicast group and the enhancement layer jointly provided by a base station-type RSU and a UAV base station.

C. CONTENT-ORIENTED EDGE CATCHING
Superior to traditional cellular networks, caching nodes can be placed at the edge of the wireless network to store frequently requested content from users. Edge caching sinks content to the edge of the wireless network, helping to reduce mobile data traffic in the backhaul network, reduce content delivery latency, and increase network throughput. Wireless edge caching technology uses edge nodes to obtain network state information such as wireless channel conditions, traffic patterns, and user mobility patterns. Especially for video content with high data volume, access from the edge can largely reduce the traffic load in the backhaul link, reduce power loss, and improve user quality of service (QoS) and user experience (QoE). Caching strategy design is closely related to the direction of cache power consumption, path selection, content delivery, multicast coding, etc. In addition, the dynamic nature of video content requests and user mobility have a significant impact on caching effectiveness.

Vehicle terminals are intelligent and will accelerate the intensity of requests for data. Therefore, caching part of the data in the RSU for vehicle use can reduce the data traffic pressure on the core network caused by vehicle requests. However, in the actual application scenario, the high-speed mobility of vehicles leads to more frequent disconnections and connections between vehicles and RSUs. The network topology will also become more frequent and complex. In summary, research on cache deployment for telematics needs to focus on vehicle mobility and vehicle path analysis. This will improve the cache utility and resource utilization. A study of the literature reveals that mobility parameters can be substituted into the objective function for optimizing cache utility. The analysis yields relatively better caching strategies by reducing the average data download from macro base stations.

III. THE PROPOSED SYSTEM MODEL
The intelligent vehicle-road collaboration system architecture proposed in this paper contains five layers. From bottom to top, they are the car-side terminal layer, the roadside layer, the network layer, the cloud layer, and the user application layer. At the network layer, 5G base station type RSUs and drone mobile base stations are used to work together to better allocate network resources for scalable coded video. Based on user mobility analysis, a relatively better edge cache strategy is obtained. Jointly, we consider the vehicle side, roadside and edge side to improve the utilization efficiency of limited network resources provide a practical and effective overall service architecture for video application scenarios of the Internet of vehicles.

A. MULTIMEDIA CONTENT DISTRIBUTION NETWORK ARCHITECTURE
In this paper, a simple heterogeneous wireless network environment is assumed for analysis, consisting of a single macro base station, a single 5G base station type RSU and a single UAV mobile base station. The macro base station, the base station type RSU and the UAV base station each serve multicast groups within their coverage area. The SVC encoded video is divided into two layers: the base layer and the enhancement layer. The macro base station provides the base layer and the enhancement layer, the base station RSU provides the enhancement layer based on user mobility, and the UAV base station provides the enhancement layer for mobile users in relatively remote locations. The user first receives the base layer from the macro base station and then decides the relationship based on location information and video reception rate and other conditional factors. The base station provides the enhancement layer. Based on the actual application scenario, it can be assumed that the distribution...
state of users at consecutive time points can be divided into numerous static distributions by time slots. The information of the surrounding environment at the current time point and the previous time point is used to help decide the location of the UAV base station and the resource allocation strategy. The network services are continuously and iteratively updated according to the mobility of users.

The user set is set to $U$, and the total bandwidth resource is denoted as $B$. The bandwidth allocated to the base layer for user multicast group provisioning is denoted as $B_b$. The remaining bandwidth $B - B_b$ is further allocated to the enhancement layer, which consists of 3 main parts. Among them, $B_{p,m}$ corresponds to the macro base station delivery enhancement layer, $B_{p,r}$ corresponds to the base station type RSU delivery enhancement layer, and $B_{p,d}$ corresponds to the UAV base station delivery enhancement layer.

Based on line of sight (LoS) probabilistic channel modeling, the LoS and NLoS connection path loss can be calculated based on the UAV height, angle, horizontal distance and other information. From this, the average path loss between the UAV base station $d$ and user $u$ can be obtained by the formula, denoted as $\delta_{d,u}$:

$$\delta_{d,u} = p_{\text{LoS}} \cdot \delta_{\text{LoS}} + (1 - p_{\text{LoS}}) \cdot \delta_{\text{NLoS}}$$  (1)

where $p_{\text{LoS}}$ is the LoS connection probability between the UAV base station $d$ and user $u$. $\delta_{\text{LoS}}$ and $\delta_{\text{NLoS}}$ denote the LoS connection path loss and NLoS connection path loss between the UAV and the user, respectively. The channel gain can be further obtained from the following:

$$g_{d,u} = 10^{-\frac{\delta_{d,u}}{10}}$$  (2)
In the coverage area of the macro base station, users requesting video resources need to go through the macro base station to obtain the base layer. To achieve a bandwidth allocation saving scheme based on the satisfied rate, the minimum bandwidth required for the base layer can be calculated from the rate. \( \delta_{m,u} \) denotes the average path loss between macro base station \( m \) and user \( u \).

\[
\delta_{m,u} = \bar{\delta}_{\text{LoS}} + \epsilon_{\text{LoS}} \log_{10} \sqrt{d_{m,u}^2 + h_m^2} \quad (3)
\]

\( \bar{\delta}_{\text{LoS}} \) denotes the reference distance path loss compensation under the LoS connection, and \( \epsilon_{\text{LoS}} \) denotes the path loss index. \( d_{m,u} \) is the horizontal distance between the user and the macro base station, and \( h_m \) denotes the height of the macro base station from the ground. Thus, the channel gain can be further obtained by calculating the following:

\[
g_{m,u} = 10^{-\frac{\delta_{m,u}}{10}}. \quad (4)
\]

Since the channel gain of the base layer multicast group is based on the worst user, it can be expressed as

\[
g_{\text{min},m,u} = \min_{u \in U} \{ g_{m,u} \}. \quad (5)
\]

Assuming that the received rate is \( v_b \) and the transmit power is \( p_m \), the required bandwidth of the base layer is calculated based on Shannon’s formula:

\[
B_b = \frac{v_b}{\log_2 \left( 1 + \frac{p_m g_{\text{min},m,u}}{\sigma^2} \right)} \quad (6)
\]

where \( \sigma^2 \) represents Gaussian noise.

The enhancement layer is provided for the user multicast group, which is jointly provided by the macro base station, the 5G base station type RSU, and the UAV base station. The channel capacity of user \( u \) and the three stations can be expressed in order as

\[
C_{m,u} = B_{p,m} \log \left( 1 + \frac{p_m g_{\text{min},m,u}}{\sigma^2} \right) \quad (7)
\]

\[
C_{r,u} = (B - B_b - B_{p,m} - B_{p,d}) \log \left( 1 + \frac{p_r g_{r,u}}{\sigma^2} \right) \quad (8)
\]

\[
C_{d,u} = (B - B_b - B_{p,m} - B_{p,r}) \log \left( 1 + \frac{p_d g_{d,u}}{\sigma^2} \right) \quad (9)
\]

\( p_r \) and \( p_d \) denote the transmit power of the 5G base station type RSU and UAV base station, respectively. \( g_{r,u} \) and \( g_{d,u} \) denote the channel gain of the corresponding base station.
problem of maximizing the enhancement layer received by the user. This can be expressed by (10).

$$\max \sum_{u \in U} \left( \gamma_{m,u} + \gamma_{r,u} + \gamma_{d,u} \right)$$

$$\gamma_{m,u} + \gamma_{r,u} + \gamma_{d,u} \leq 1$$

In addition, the constraints $\gamma_{m,u}$, $\gamma_{r,u}$, and $\gamma_{d,u}$ need to be satisfied. The three are binary variables. Let $v_0$ be the augmentation layer reception rate. When $C_{m,u} \geq v_0$, a $\gamma_{m,u}$ of one means that the augmentation layer information can be received, and zero means that it is not received. $\gamma_{r,u}$ and $\gamma_{d,u}$, similarly, distinguish whether the augmentation layer information is received by zero and one. Since users are mobile, the optimization problem can be solved optionally by a neural network algorithm.

Based on the algorithmic idea of DDPG, first, the critic current network, critic target network, actor current network and actor target network are clarified. As the name implies, the target network represents the replication of the current network. The actor current network is used for the policy parameter update. The overall idea can be understood as generating the next state and reward $R$ based on the current state and action. The actor target network is used to select the next action based on the next state. The target network parameter $\alpha^{o'}$ is periodically replicated based on the current network parameter $\alpha^o$. The critical current network is used to update the network parameter $\alpha^Q$ and calculate the $Q$ value $Q(S, A, \alpha^Q)$. The critical target network is used to calculate the $Q'$ value of the next state and action, which is $Q'(S', A', \alpha^{Q'})$. In each iteration, the target network is updated using the current network.

$$\alpha^Q \leftarrow \tau \alpha^Q + (1 - \tau) \alpha^{Q'}$$

$$\alpha^{o'} \leftarrow \tau \alpha^{o'} + (1 - \tau) \alpha^{o'}$$

$$R = \frac{(1 - \rho) \sum_{u \in U} \gamma_{m,u} + \rho \sum_{u \in U} \left( \gamma_{r,u} + \gamma_{d,u} \right)}{N_{user}}$$

where $o'$ denotes the exploration strategy, which implements the exploration process of reinforcement learning by adding noise. The reward takes the form of a weighted average of the service rates of macro base stations, 5G base station type RSUs and UAV base stations in the augmentation layer. Meanwhile, the actor takes the user’s location information as the input of the system. The critic takes the location information and the actor output action as the input, thus outputting the score $R$. $N_{user}$ denotes the number of users. The analysis of research results from other literature shows that better performance is often achieved when $\rho$ takes a larger value.

SPN is an innovative technology system for 5G transmission networks. The forwarding plane can realize the isolation and bandwidth flexible scheduling function of telematics services based on FlexE technology. In subsequent research, further consideration can be given to combining slicing to achieve physical isolation of differentiated bearers, thus ensuring lower delay and jitter sensitivity.

**B. CACHING STRATEGY**

Due to the uniqueness of the telematics scenario, most vehicles are moving at a high speed. Therefore, during video data download, vehicles may connect to different base stations, thus limiting the caching utility. To improve the efficiency of content delivery during mobility, caching techniques have been introduced in telematics. Statistical analysis algorithm tools can be used for modeling predictions of mobility, thus helping to optimize edge caching policy design and improve the cache hit ratio. The RSU, as one of the network nodes, is tasked to store content data in the telematics environment. However, due to the combined effect of vehicle mobility and the storage limitation of the RSU itself, it connects to the macro base station to obtain the remaining data when it has not finished downloading the requested content. To alleviate the pressure on macro base stations, this paper considers analyzing vehicle paths through Markov chains so that the caching strategy can be optimized and used in the overall architecture proposed in this paper. To cope with the highly variable link throughput during movement, a combination of SVC and a multicast mechanism is used to instantly cope with fluctuating network conditions. The method is characterized by encoding frames into a base layer (BL) and multiple enhancement layers (EL), where the higher the number of EL, the higher the video quality. Although the method’s decoding relies on information from the base layer, it can accept packets lost from the enhancement layer. For the purpose of computational analysis and to provide the user with the most enhancement layers, a scenario with only one enhancement layer is assumed. Each video file data point is stored in a server that supports real-time extraction and transmission.

Assume that $X$ RSU devices $\{RSU_1, \ldots, RSU_X\}$ are distributed in the system and that their coverage areas are guaranteed to be nonintersecting. RSUs can both use their original storage capacity to cache and help macro base stations complete their transmission tasks. Once a video file is requested, it must be completed within $T$ time slots. This reduces the higher costs associated with connecting further macro base stations for the uncompleted portion of the download.

Based on experience, there is a strong correlation between the high popularity of a video and whether it is stored or not. Since video content popularity has been well studied in the academic research community, the Zipf distribution is used to model the SVC video content popularity. Therefore, this chapter sets the requested video popularity to be known and denotes it as $P_u \in [0, 1]$. This chapter considers a video library containing $M$ video files, denoted as $V_0 \in \{V_1, V_2, \ldots, V_i, \ldots, V_M\}$.

When the vehicle is covered by the $x$th RSU at the $t$th time slot, the probability of this situation is recorded as $p[BS_i]$ and the required data volume is $B_{t,i}$. The storage capacity of the $x$th roadside unit $SU_x$ is recorded as $C_x$. The transmittable data volume per time slot is recorded as $R_x$. The cache policy is recorded as $\{f_{x,i}\}_{i=1}^M$. $f_{x,i}$ represents file $V_i$ corresponding to the amount of cache in its $SU_x$. To guarantee transmission, policy $F$ needs to satisfy $\sum_{i=1}^M f_{x,i} \leq C_x$. **Z. Ma, S. Sun: Research on Vehicle-to-Road Collaboration and End-to-End Collaboration**
To achieve the average data volume downloaded by the macro base station as less than $D_{\text{MBS}_i}^{\text{avg}}$, the amount of RSU data required by the vehicle user to request $V_i$ and the amount of data required by the MBS to download are denoted as

$$D_{\text{RSU}_i} = \sum_{t=1}^{T} \sum_{x=1}^{X} p_B [B_{x,i}^t] B_{x,i}^t$$

(15)

$$D_{\text{MBS}_i} = B_i - \sum_{t=1}^{T} \sum_{x=1}^{X} p_B [B_{x,i}^t] B_{x,i}^t$$

(16)

$$D_{\text{MBS}_i}^{\text{avg}} = \sum_{i=1}^{M} p_i D_{\text{MBS}_i}$$

(17)

where the amount of data of a single video file is denoted as $B_i$ and the requested probability is denoted as $p_i$. The optimization problem can be expressed as

$$\min_S D_{\text{MBS}_i}^{\text{avg}}$$

(18)

In the analysis of the model based on a hierarchical Markov chain, the root state zero represents the state that the user makes a request for the file, each layer represents a time slot, and the possible cases in the chain are passed through the sequence of states $\{S_1, S_2, \ldots, S_i\}$. The movement path of the vehicle is predicted by defining it as the RSU path connected at $t$ time slots after requesting the video. Based on the actual movement of the vehicle, the vehicle can connect multiple time slots under the same RSU. Then, it can be equivalently understood that the vehicle can be connected to at most $T$ different RSUs.

Therefore, according to the amount of data $f_{x,i}$ of $V_i$ cached by RSU$x$ and the transmission rate $R_x$, the amount of data available during the connection is $\min \{f_{x,i}, T \cdot vR_x\}$, where $T \cdot v$ denotes the duration in the same RSU after requesting the file. $N_{T \cdot v}$ denotes the number of time slots that stay in the same RSU. Then, the probability of being connected to any RSU on the roadside for time $t$ can be written as $p [N_{T \cdot v} = t]$ and the objective function can be further transformed as

$$\min_{S_T} B_i - \sum_{i=1}^{M} p_i \sum_{t=1}^{T} \sum_{x=1}^{X} p [N_{T \cdot v} = t] \min \{f_{x,i}, tR_x\}$$

(19)

Once the vehicle mobility is analyzed, the caching policy can be further developed based on the time gap of the vehicle staying at the RSU.

$T \leq T_{\text{RSU}_i}^{\text{min}}$ indicates that the vehicle cannot collect the entire data volume in $T$ time slots and needs to resort to MBS. Minimizing $D_{\text{MBS}_i}^{\text{avg}}$ at this point is equivalent to maximizing $D_{\text{RSU}_i}$. A slope-based distributed caching strategy is chosen. By maximizing each individual RSU download, the entire path is maximized.

$T \geq T_{\text{RSU}_i}^{\text{min}}$ indicates that data can be fetched from the roadside unit. The greedy caching policy is chosen, still with the objective of minimizing $D_{\text{MBS}_i}^{\text{avg}}$. After first determining the optimal policy based on the previous algorithm, we proceed to determine whether, in each RSU, candidate video files need to be added or reduced. The capacity is increased for files with higher popularity and reduced for those with lower popularity. Thus, the policy of allocating cache capacity for each roadside unit completes the update iteration.

**IV. EXPERIMENTAL RESULTS**

The simulation in this paper is based on a Mac OS system with a M1 CPU. The software platform is based on Python version 3.8. By adjusting the hyperparameters, the mean value of the solution is run to observe the simulation results. The trend of the REVERSE is plotted for three different parameters: 0.55, 0.6 and 0.65. Based on the experimental results, it is clear that the model can be used to achieve better performance with stable convergence. This proves that the proposed service architecture model is effective.

At the same time, the results of multiple schemes are compared by adjusting the function and layer changes. To better support that the scheme is practical and feasible, the proposed scheme is denoted as DU. i) By replacing the activation function of the actor network with a sigmoid activation function and labeling it as DU-Sig. ii) By replacing the BatchNorm layer with a LayerNorm layer and recording it as DU-LN. iii) The results with three different parameters show that all can achieve effective convergence. Specifically, the average rewards of DU-Sig are lower than those of the other two. The DU-LN is also able to converge smoothly, but the final rewards are lower than those of the DU structure.
In this paper, an intelligent collaborative service architecture for multimedia content distribution is proposed to optimize and improve the system performance for the telematics scenario proposed. The proposed scheme is effective in optimizing and improving video contents with higher popularity while satisfying the constraints. The scheme develops a corresponding edge caching strategy by caching the most popular contents at the base stations and thus their pressure is reduced. The scheme considers network resource allocation deployment and wirelessly caches contents to improve the performance of the whole system. The user perception of video quality is optimized by combining a RSU 5G base-station and an UAV mobile base station, thereby solving dynamic deployment and bandwidth allocation problems more efficiently and intelligently through a variant of the actor-critic algorithm. At the same time, vehicle mobility is analyzed based on Markov chains to optimize the average download data volume of macro base stations and thus their pressure is reduced. The scheme develops a corresponding edge caching strategy by caching video contents with higher popularity while satisfying the user quality of service. The data simulation results show that the proposed scheme is effective in optimizing and improving the system performance for the telematics scenario proposed in this paper.

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