IEEE Access
Multidisciplinary : Rapid Review : Open Access Journal

Received 22 July 2022, accepted 5 August 2022, date of publication 16 August 2022, date of current version 19 August 2022.
Digital Object Identifier 10.1109/ACCESS.2022.3198667

RESEARCH ARTICLE

Optimization of Caching Update and Pricing Algorithm Based on Stochastic Geometry Theory in Video Service

WENBIN FU
School of Information and Communication Engineering, Beijing University of Posts and Telecommunications, Beijing 100876, China
e-mail: fuwenbin@bupt.edu.cn

ABSTRACT In order to meet the growing needs of vehicle users for high-quality video experience, it can be used caching technology and transcoding technology to meet the needs of vehicle users. However, due to the complexity of the practical scene, when improving the service quality of vehicle users, it is necessary to consider the mobility of vehicle users and the utilization of network resources (caching, base station computing resources, backhaul links, etc.). In order to deal with the impact of vehicle mobility and network resource usage on the acquisition of video segments by vehicle users, this paper not only takes vehicle mobility into full account in mathematical modeling, but also proposes caching update algorithm and pricing algorithm. Firstly, considering the transcoding between different versions of video, the base station takes into account the value of energy consumption when caching video segments. Then, according to the different use of caching, base station computing resources and backhaul links by vehicle users, a pricing algorithm of network resources is proposed to improve the flexibility of network resource utilization. Finally, the mathematical model is optimized by convex optimization theory, and the influence of caching update algorithm on caching gain and the impact of pricing algorithm on network resource utilization are shown through simulation. The simulation results show that the total gain, caching gain, transcoding gain and flexibility of network resource utilization are improved significantly.

INDEX TERMS Vehicle, video transcoding, mobility, caching update, pricing algorithm, network resource optimization.

I. INTRODUCTION

With the continuous development of network technology, a large number of multimedia providers (such as TikTok, YouTube, HuLu, and Yahoo) are emerging, which makes the number of videos explosive growth. At the same time, these multimedia providers are required to provide a large number of different versions of video to meet the needs of different types of mobile devices. A wide variety of videos an different versions of videos lead to video traffic occupying a large number of network resources, which brings great operational pressure to network operators. In Cisco's report [1], mobile video traffic will accounts for 82 percent of global mobile data traffic in 2022. With the continuous improvement of the performance of various portable devices, video services are widely used in drivers and passengers [2]. In recent years, the development of Vehicle to Infrastructure (V2I) has attracted more and more attention of scholars and vehicle manufacturers [3]. The progress of vehicle networking technology has promoted the development of vehicle Internet and vehicle computerization [4]. The increasingly powerful data processing ability of vehicles promotes the progress of vehicle entertainment and visual driving assistance technologies [5]. The demand for video resources from vehicles and users' mobile devices makes vehicle users become the main contributors of mobile data traffic consumption. The explosive growth of mobile data traffic demands has brought huge challenges to network operators. In addition, vehicle users are growing in

The associate editor coordinating the review of this manuscript and approving it for publication was Giovanni Pau.

both developed and developing countries [6], [7]. Therefore, how to solve the problem of video service quality of vehicle users will become one of the urgent problems for network operators in the future.

In response to the growing demand for mobile video data traffic, researchers mainly consider from two aspects: one is to increase the network transmission rate; the other is to consider from the vehicle user to obtain the required video through caching, video transcoding and backhaul link. In terms of how to increase the network transmission rate, scholars are mainly committed to the research of coping with the growing mobile data traffic through massive Multiple Input Multiple Output (MIMO) technology and Ultra Dense Networking (UDN) technology. Massive MIMO technology mainly improves the data transmission rate of the system by improving the spectrum efficiency and energy efficiency. This method can cope with the increasing data traffic demand to a certain extent [8]. However, pilot pollution is a difficult problem to be solved in practical application of massive MIMO technology [9]. UDN technology is to achieve the purpose of spectrum reuse per unit area by increasing the density of access points [10]. Although UDN technology can increase the data transmission rate by continuously increasing the density of access points, the increasing density of access points will bring the problem of increasing the handover frequency to mobile vehicle users.

On the other hand, vehicle users can obtain the required video resources through caching technology. Caching has the advantages of convenient deployment, low price, reducing the burden of backhaul link and reducing data traffic, which makes caching receive great attention in network deployment [11]. Caching research focuses on two aspects: caching scheme and caching update scheme. In terms of caching scheme, since the size of cache space cannot be infinite, a scheme is needed to decide which video content to cache to improve the efficiency of caching. In the existing video segment caching schemes, video segments are mainly cached according to the popularity of video segments [12]. In terms of caching update scheme, the main update schemes of caching include: usage frequency scheme, the hierarchical scheme, the lowest request frequency scheme and First Input First Output (FIFO) Scheme [13]. Although the application of caching technology in mobile network has many advantages, but the caching technology also has shortcomings. The size of caching space and time delay are often the main problems restricting caching deployment [14].

Vehicle users can also obtain the required video segments through video transcoding technology. Video transcoding technology is widely used in adaptive streaming media scenarios due to its advantages of reducing caching pressure and decreasing backhaul link resource requirements [15]. Video transcoding technology mainly includes two methods: the first method is to achieve transcoding target through hardware assistance, and the second method is to achieve transcoding by consuming computing resources [16]. In the second method to realize video transcoding, scholars mainly focus on providing users with the required video version through base station and cloud network [17]. However, the strong advantages of video transcoding technology can not hide the problems caused by its two main shortcomings. One is the energy consumption problem caused by the huge computing resources required by transcoding technology [18], which will make the development of this technology deviate from the direction of green energy Internet. The other problem is the time delay caused by video transcoding technology [19], which will affect the user experience. How to solve these two shortcomings of video transcoding technology is also a problem that scholars are committed to overcome.

From the above analysis, it can be seen that vehicle users have certain limitations whether they obtain the required video segments through caching scheme, video transcoding scheme or backhaul link scheme. If the advantages of each of these three schemes to obtain video segments can be fully utilized and cooperate with each other to provide video services for vehicle users, it will have a better effect than obtaining the required video segments through only one scheme. Therefore, how to combine these three video acquisition schemes to provide vehicle users with the video resources they need has aroused scholars' research [15]. In order to compare the advantages and disadvantages of these three schemes, a unified standard is needed to evaluate the three schemes. Through the comparison of the three schemes, the best video acquisition scheme is selected to provide video resources for vehicle users. To solve this problem, this paper proposes a caching update algorithm and pricing algorithm. Caching update algorithm is used to improve the utilization efficiency of caching resources, and pricing algorithm is used to improve the flexibility of network resources. In this paper, it is assumed that the benefits brought by network resources to network operators are called gains. Caching resources, video transcoding resources and backhaul link resources are priced and commercialized through the pricing algorithm. By comparing the gain value to determine the best of the three schemes, so as to provide the best video segment acquisition scheme for vehicle users.

In this paper, we consider the impact of the pricing mechanism of network resources on the use of network resources, the impact of caching update scheme on the total gain, and the impact of the mobility of vehicle users on the total gain. The contributions of this paper are mainly as follows:

- This paper proposes a pricing algorithm, which can adjust the unit price of backhaul link, transcoding and caching to control the way vehicle users get the video segments they need, so as to improve the flexibility of using network resources.
- High version video segments can be converted to lower version video segments. Sometimes the video transcoding gain is greater than the caching gain. When updating the caching, the video segment with the minimum gain should be removed from the caching first. Therefore, this paper proposes a caching update algorithm considering

caching gain and transcoding gain, which can improve the efficiency of caching utilization.
- There is no data transmission in the process of vehicle handover base station. Due to the mobility of vehicle users, it is necessary to handover to different base stations to obtain video services. Different from other vehicle users' access to video services, this paper takes the influence of handover process into account when calculating network gain. into account when calculating network gain.
- Because the boundary of the base station is abstract and uncertain, it is not perfect to use the honeycomb boundary to analyze the handover process of vehicle users. In this paper, the stochastic geometry theory is used to analyze the handover process of vehicle users, which can transform the abstract boundary problem of base station into a probability problem, so as to analyze the backhaul link gain more accurately.

The rest of this paper is structured as follows: Section II introduces the related works. Section III introduces the system model and the related assumptions. Section IV introduces the formulation and solution of the problem. In the Section V, the caching update algorithm and pricing algorithm are proposed in the process of vehicle users acquiring video. In the Section VI, the results of the paper are simulated and compared. Finally, we summarize the content of the paper in Section VII.

II. RELATED WORKS

Considering the advantages of caching, such as reducing the transmission of duplicate data, improving spectrum efficiency and easy deployment, more and more researchers begin to pay attention to the problem of caching in recent years [20]. The caching can be placed on the device side or the base station side. In research of caching placement on the device side, the author designs a Device to Device (D2D) encoding free caching scheme in [21], which can minimize the caching load. In [22], author groups the caching size and content size of the user device, and proposes a packet caching algorithm based on this grouping strategy to improve the caching hit rate of the device side. In [23], the author proposes a caching deployment algorithm based on user preference at the device side, in which the caching deployment algorithm has a good effect in reducing the transmission delay and improving the caching hit rate. In the research of base station layout caching, the author proposes a hybrid content caching design in [24], which can reduce transmission delay by optimizing content caching location. In [25], the author studies an idea of joint bandwidth allocation and caching to reduce transmission delay.

The emergence of video transcoding technology solves the problem that users need different video versions in different network conditions and different devices. As video transcoding is a computing intensive business, researchers mainly focus on how to improve the quality of video transcoding and reduce the cost of resource consumption [26]. In order to improve the video quality after transcoding, in [16], a method combining software and hardware is proposed to replace transcoding on media server. In order to ensure the robustness of transcoding video, the researchers propose a scheme to improve the transcoding ability of devices by using edge computing in [27]. In order to reduce the impact of handover delay on video quality of service, in [28], a location prediction sensing algorithm which can reduce transcoding delay is proposed. In order to reduce the consumption of network resources, in [29], researchers propose a real-time video transcoding system based on cloud network. In [30], researchers propose a three-stage Steinberg game theory scheme to reduce the average delay and network overhead of video transcoding. In [31], the researchers study a cloud based dynamic adaptive video transcoding framework, which can significantly reduce the network traffic of the core network.

In the development process of vehicle users' access to video services, researchers mainly improve the network experience of vehicle users by optimizing resource allocation and using other auxiliary means. In the research of resource optimization, the author proposes a joint optimization algorithm of Vehicle to Vehicle (V2V) and Long Term Evolution (LTE) communication in [32], which can significantly improve the service quality of vehicle users. In order to improve the service quality of vehicle users, in [33], researchers propose a resource allocation scheme based on semi Markov process. In the research on the use of caching and video transcoding, in [34], researchers propose a caching scheme combining communication service layer and vehicle caching to reduce the cost. In [35], the author proposes a method to caching video into the caching of small base station, through that optimization method to reduce data traffic. In [36], the author proposes an optimization method that combines video transcoding technology, base station caching technology and backhaul link technology, which can improve the utilization efficiency of multicast network resources.

At present, although scholars have done a lot of research on caching, video transcoding and backhaul link, the research on providing video services for vehicle users with these three schemes at the same time has not been fully completed. The existing method of providing video services for vehicle users through a single scheme is difficult to make good use of network resources. Therefore, this paper proposes a scheme that can flexibly use different network resources to provide better video segment services for vehicle users, and studies the related problems of improving caching efficiency. In the next section, the specific scheme proposed in this paper will be introduced in detail.

III. SYSTEM MODEL AND PROBLEM ANALYSIS

In this section, we mainly introduce the system model in detail, and formulate the backhaul link gain, caching gain, caching consumption and video transcoding consumption of vehicle users.

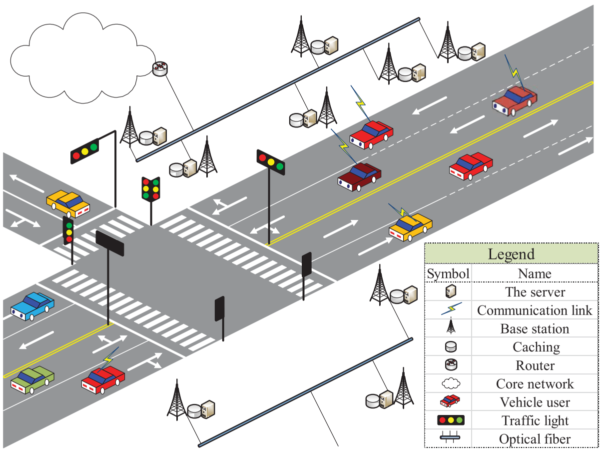

FIGURE 1. Vehicle networking system model.

A. SYSTEM MODEL

As shown in Fig. 1, it is assumed that vehicle users move within the coverage of single layer base stations, and these base stations providing network services for vehicle users have the same storage capacity and computing capacity. The power of these base stations is assumed to be P, and the set of these base stations can be expressed as $\mathbb{N} = \{1, 2, 3, \ldots, N\}$. Assuming that the distribution of base stations follows the Poisson distribution of density λ_s, the nearest base station provides network services for vehicle users. The distance between the vehicle user and the nearest base station is expressed as d_1. Similarly, the distance between the nst base station and the vehicle user can be expressed as d_n, and all base stations can communicate with the remote core network through backhaul links. Suppose that there are R different videos in the network, and $R = \{1, 2, 3, \ldots, r\}$, r_k represents the kth different version of the rth video, and the k value is inversely proportional to the size of the video segment. In this paper, $S_{r_k}(I_0) = \{1, 2, 3, \ldots, i, \ldots\}$ is the set of all video segment of r_k, and $S_{r_k}^{size}(i)$ is the size of the ith video segment of r_k. Different versions of video segments have different sizes, but have the same video segment length L_r (in seconds). The notations and definitions used in this paper are listed in Table 1.

B. VIDEO REQUEST PROCESSING MODEL

When the vehicle user has a video demand, the vehicle user will connect with the nearby base station. As shown in Fig. 2, when the vehicle user submits video service request, The base station will process the video requests of the vehicle users in three ways: in the first case, if the video segment required by the vehicle user is in the caching, the vehicle user will directly obtain the required video segment from the caching. In the second case, if the video segment required by the vehicle user is not in the caching, but the higher version of the video segment is stored in the caching, and the video transcoding consumption is less than the backhaul link consumption, the vehicle user will obtain the required video segment through transcoding. In the third case, when there is neither the video segment version required by the vehicle user nor a higher version of the video version required by the vehicle user in the caching of the base station, or the transcoding consumption of the video is greater than the consumption of the backhaul link, the vehicle user will obtain the video segment required from the backhaul link.

For the convenience of expression, $\Psi_{r_k}^{c}(i)$, $\Psi_{r_k}^{t}(i)$ and $\Psi_{r_k}^{b}(i)$ are used to represent the ith segment of r_k-version video obtained by vehicle users through caching, base station video transcoding and backhaul link, respectively. In order to guarantee the service quality of vehicle users and limit the redundant transmission, each video segment of the video version required by vehicle users will only provide services for

TABLE 1. List of key notations.

Notation	Definition
P	Transmission power of the base station
$\mathbb{N}$	The set of base stations
λ_s	The density of base stations
d_n	The distance between the nst base station and the vehicle user
r_k	The kth different version of the rth video
$S_{r_k}(I_0)$	The set of all video segment of r_k
$S_{r_k}^{size}(i)$	The size of the ith video segment of r_k.
$\Psi_{r_k}^{c}(i)$	The ith segment of r_k-version video obtained by vehicle users through caching
$\Psi_{r_k}^{t}(i)$	The ith segment of r_k-version video obtained by vehicle users through transcoding
$\Psi_{r_k}^{b}(i)$	The ith segment of r_k-version video obtained by vehicle users through backhaul link
V_{tot}	The total number of all videos in the network
$P_{V_{tot}}(l)$	The conditional probability that the video segment requested by the vehicle user is the lth popular
$\bar{v}$	The average speed of the vehicle user
$\bar{C}(n)$	The average data transmission rate of the backhaul link required by base station n
B	The bandwidth allocated to each vehicle user
H	The probability that the vehicle user does not perform handover
$F(\bar{v})$	The handover delay
θ	The handover threshold
$h(z)$	Channel gain
t_h	The time required for a vehicle user to handover between different base stations
$h(z)$	The channel gain obtained by the vehicle user from the zth nearest interfering base station
I	Noise power density
f_0	Server CPU frequency
H_t	Time spent by user handover base station each time
η_{fem}	Path loss index
S_c	Base station available caching size
B_{ev}	Bandwidth allocated to each vehicle user

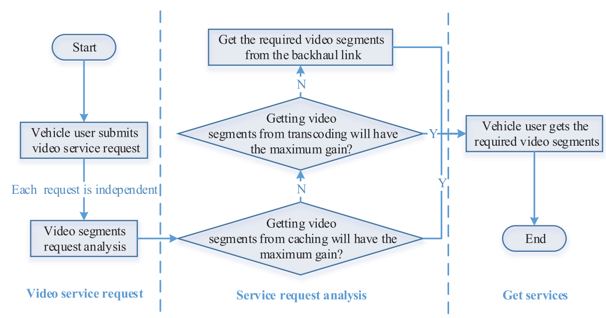

FIGURE 2. Flowchart of video service for vehicle users.

vehicle users in one way. Therefore, the following equation can be obtained:

$$\Psi_{r_k}^{c}(i) + \Psi_{r_k}^{t}(i) + \Psi_{r_k}^{b}(i) = 1, \forall i \in S_{r_k}(i). \quad (1)$$

C. INITIAL CACHING MODEL

Each base station receives a series of video requests, which are independent of each other. The total number of all videos in the network can be expressed as $V_{tot} = \sum_{k=1}^{g}\sum_{r=1}^{m} r_k$. All videos are sorted in descending order according to their popularity. According to Zipf's law, we can get the conditional probability $P_{V_{tot}}(l)$ that the video segment requested by the vehicle user is the lth popular, which can be expressed as:

$$P_{V_{tot}}(l) = \frac{W(l)}{\sum_{l=1}^{V_{tot}} W(l)}, \quad (2)$$

where w can be expressed as:

$$W(l) = \frac{1}{l^{\tau}}, \quad (3)$$

where τ is a positive number and $\tau \in [0, 1.3]$.

D. DATA TRANSMISSION

When the average speed of the vehicle user is $\bar{v}$, the video segment request is sent to the base station n. It is assumed that the distribution of base stations follows the Poisson distribution of density λ_s, and the video segments required by vehicle users are obtained from the remote core network. According to [37], [38],the average data transmission rate of the backhaul link required by base station n can be expressed as follows:

$$\bar{C}(n) = BH\left(1 - F(\bar{v})\right)\ln(1+\theta), \quad (4)$$

where B represents the bandwidth allocated to each vehicle user, H represents the probability that the vehicle user does not perform the base station handover, $F(\bar{v})$ represents the handover delay, and θ represents the handover threshold.

E. HANDOVER DELAY

According to corollary 1 of [39], when the vehicle user moves at the average speed $\bar{v}$ in a single layer base station, the handover frequency of the vehicle user between different base stations can be expressed as follows:

$$F(\bar{v}) = \frac{4\bar{v}\sqrt{\lambda_s}}{\pi}. \quad (5)$$

It is assumed that the time required for a vehicle user to handover between different base stations is t_h, and it is assumed that there is no data transmission between the vehicle user and the base station during the handover process. Then the time spent by vehicle users to switch base stations in unit time is as follows:

$$F(\bar{v}) = \frac{4t_h\bar{v}\sqrt{\lambda_s}}{\pi}. \quad (6)$$

F. PROBABILITY OF NOT PERFORMING HANDOVER

When the SINR of the current base station received by the vehicle user is less than a threshold, the vehicle user will handover to the next base station, and all network services of the vehicle user are provided by the next base station. In this paper, the probability of vehicle user handover to the next base station is defined as the handover probability of vehicle users. From the above description, the mathematical expression of the probability that the vehicle user does not perform the handover can be expressed as follows:

$$H = P\left\{\frac{P|h(1)|^2 d_1^{-\alpha}}{\sum_{z\in\mathbb{N},z\neq 1,} P|h(z)|^2 d_z^{-\alpha} + I} > \theta\right\}, \quad (7)$$

where $\alpha > 2$ represents the path loss index, P is the transmitting power of base station, $h(1)$ represents the channel gain obtained by the vehicle user connecting to the nearest base station, $h(z)$ represents the channel gain obtained by the vehicle user from the zth nearest interfering base station, and I represents the additive white Gaussian noise received by the vehicle user.

It is assumed that the channel gain $h(z)$ follows a complex Gaussian random distribution with independent and identically distributed, $h \sim CN(0, \sigma^2)$. We can obtain that $|h(z)|^2$ obeys the χ^2 distribution of parameter 2. The probability density function of $|h(z)|^2$ can be expressed as follows:

$$f_{|h(z)|^2}(y) = \frac{y}{4\Gamma(2)} e^{-y/2}, y > 0, \quad (8)$$

where y represents a variable greater than zero.

Lemma 1: When the vehicle user chooses the base station to serve itself according to the SINR value, the probability that the vehicle user does not handover the base station can be expressed as follows:

$$H = 2\pi\lambda_s \int_0^{\infty} d_1 \exp\left[H_0(f)\right] d(d_1), \quad (9)$$

where equation $H_0(f)$ can be expressed as:

$$H_0(f) = -\frac{\theta I d_1^{\alpha}}{2P} - \pi\lambda_s\left(H_1(f) + H_3(f)\right), \quad (10)$$

where $H_1(f)$ and $H_3(f)$ can be represented by Gaussian hypergeometric functions, and the two equations can be expressed as follows:

$$H_1(f) = d_N^2\left[1 - {}_2F_1\left(2, -\frac{2}{\alpha}; 1 - \frac{2}{\alpha}; -\frac{\theta d_1^{\alpha}}{d_N^{\alpha}}\right)\right], \quad (11)$$

$$H_3(f) = d_1^2 {}_2F_1\left(2, -\frac{2}{\alpha}; 1 - \frac{2}{\alpha}; -\theta\right). \quad (12)$$

Proof:

Suppose $\frac{P|h(1)|^2 d_1^{-\alpha}}{\sum_{z\in n,z\neq 1,} P|h(z)|^2 d_z^{-\alpha} + I} = \frac{I_1}{I_{SBS}+I}$, according to [40], Laplace transform of I_{SBS} can obtain the following equation:

$$\mathcal{L}_{I_{SBS}}(s) = E\left(e^{-s\sum_{z\in\mathbb{N},z\neq 1,} P|h(z)|^2 d_z^{-\alpha}}\right), \quad (13)$$

where $\sum_{z\in\mathbb{N},z\neq1,} P|h(z)|^2 d_z^{-\alpha}$ represents the interference signal received by the vehicle user from other base stations except the service base station. Since the interference signals from other base stations are independent of each other, Eq. (13) can be further written as follows:

$$\mathcal{L}_{I_{SBS}}(s) = E_{\mathbb{N}}\left[\prod_{z=1}^{N}\mathcal{L}_{|h(z)|^2}\left(sPd_z^{-\alpha}\right)\right] \overset{(a)}{=} E_{\mathbb{N}}\left[\prod_{z=1}^{N}\frac{1}{\left(2sPd_z^{-\alpha}+1\right)^2}\right]. \quad (14)$$

Since $|h(z)|^2$ obeys the distribution of χ^2 with degree of freedom of 2, the following equation can be obtained by Laplace transformation of C:

$$\mathcal{L}_{|h(z)|^2}(s) = \frac{1}{(2s+1)^2}. \quad (15)$$

Therefore, we can get the result of (a) in Eq. (14). The Eq. (14) is further simplified as follows:

$$\begin{aligned}\mathcal{L}_{I_{SBS}}(s) &= \exp\left(-2\pi\lambda_s\int_{d_1}^{d_N}\left(1-\frac{1}{\left(2sP\gamma^{-\alpha}+1\right)^2}\right)\gamma d(\gamma)\right)\\ &\overset{r=\gamma^2}{=} \exp\left[-\pi\lambda_s\underbrace{\int_{d_1^2}^{d_N^2}\left(1-\frac{1}{\left(2sPr^{-\frac{\alpha}{2}}+1\right)^2}\right)d(r)}_{M}\right].\end{aligned} \quad (16)$$

If the integral part m in Eq. (16) is calculated separately, the following equation can be obtained:

$$M = \int_{d_1^2}^{d_N^2}\left(1-\frac{1}{\left(2sPd_z^{-\alpha}+1\right)^2}\right)d(r). \quad (17)$$

By change of variable the above equation, the following equation can be obtained:

$$M = d_N^2 - d_1^2 - \underbrace{\frac{2(2sP)^{\frac{2}{\alpha}}}{\alpha}\int_{2sPd_N^{-\alpha}}^{2sPd_1^{-\alpha}}(y+1)^{-2}y^{-\frac{2}{\alpha}-1}d(y)}_{M_1}. \quad (18)$$

M_1 can be further written as follows:

$$\begin{aligned}M_1 &= \frac{2(2sP)^{\frac{2}{\alpha}}}{\alpha}\int_0^{2sPd_1^{-\alpha}}\frac{y^{-\frac{2}{\alpha}-1}}{(y+1)^2}d(y) - \frac{2(2sP)^{\frac{2}{\alpha}}}{\alpha}\int_0^{2sPd_N^{-\alpha}}\frac{y^{-\frac{2}{\alpha}-1}}{(y+1)^2}d(y)\\ &= d_N^2{}_2F_1\left(2,-\frac{2}{\alpha};1-\frac{2}{\alpha};-2sPd_N^{-\alpha}\right) - d_1^2{}_2F_1\left(2,-\frac{2}{\alpha};1-\frac{2}{\alpha};-2sPd_1^{-\alpha}\right),\end{aligned} \quad (19)$$

where ${}_2F_1(:,:;:;:)$ denote Gaussian hypergeometric functions. By introducing the result of Eq. (19) and Eq. (18) into Eq. (16)), the following results can be obtained:

$$\begin{aligned}&\mathcal{L}_{I_{SBS}}(s)\\ &= \exp\left\{-\pi\lambda_s\left[d_N^2\left[1-{}_2F_1\left(2,-\frac{2}{\alpha};1-\frac{2}{\alpha};-2sPd_N^{-\alpha}\right)\right]\right.\right.\\ &\left.\left.\quad -d_1^2\left[1-{}_2F_1\left(2,-\frac{2}{\alpha};1-\frac{2}{\alpha};-2sPd_1^{-\alpha}\right)\right]\right]\right\}.\end{aligned} \quad (20)$$

By further calculation of equation H, the following equation can be obtained:

$$\begin{aligned}H &= P\left\{|h(1)|^2 > \frac{\theta I_{SBS}+\theta I}{Pd_1^{-\alpha}}\right\}\\ &= E_{d_1}\left\{E_{I_{SBS}}\left[\int_{\frac{\theta I_{SBS}+\theta I}{Pd_1^{-\alpha}}}^{\infty}\frac{y}{4}e^{-y/2}d(y)\right]\right\}\\ &\geq E_{d_1}\left\{E_{I_{SBS}}\left[e^{-\frac{\theta I_{SBS}+\theta I}{2Pd_1^{-\alpha}}}\right]\right\}\\ &= E_{d_1}\left[e^{-\frac{\theta I d_1^{\alpha}}{2P}}\mathcal{L}_{I_{SBS}}\left(\frac{\theta d_1^{\alpha}}{2P}\right)\right].\end{aligned} \quad (21)$$

The result of Eq. (20) is introduced into the above equation, which can be further written as follows:

$$H=E_{d_1}\left\{\exp\left[-\frac{\theta I d_1^{\alpha}}{2P}-\pi\lambda_s\left(H_1(f)-H_2(f)\right)\right]\right\}, \quad (22)$$

where

$$H_1(f) = d_N^2\left[1-{}_2F_1\left(2,-\frac{2}{\alpha};1-\frac{2}{\alpha};-\frac{\theta d_1^{\alpha}}{d_N^{\alpha}}\right)\right], \quad (23)$$

$$H_2(f) = d_1^2\left[1-{}_2F_1\left(2,-\frac{2}{\alpha};1-\frac{2}{\alpha};-\theta\right)\right]. \quad (24)$$

According to lemma 1 in [41], the probability density function of the distance d_1 between the user and the nearest base station can be expressed as:

$$f_{d_1}(d_1) = 2\pi\lambda_s d_1 e^{-\pi\lambda_s d_1^2}, 0 \leq d_1 \leq \infty. \quad (25)$$

Therefore, Eq. (21) can be written as follows:

$$\begin{aligned}H &= 2\pi\lambda_s\int_0^{\infty}d_1\\ &\quad \exp\left[-\frac{\theta I d_1^{\alpha}}{2P}-\pi\lambda_s\left(H_1(f)+H_3(f)\right)\right]d(d_1),\end{aligned} \quad (26)$$

where

$$H_3(f) = d_1^2{}_2F_1\left(2,-\frac{2}{\alpha};1-\frac{2}{\alpha};-\theta\right). \quad (27)$$

Therefore, the proof of lemma 1 is complete. □

G. GAIN AND CONSUMPTION OF NETWORK RESOURCES

When the video segment required by the vehicle user is not available in the caching of the base station, but there is a higher version of the video segment required by the vehicle user in the caching of the base station. The base station can transcode the higher version video segment into the video segment needed by vehicle users, and provide video services for vehicle users.

Assuming that the number of CPU cycles required to process a video segment per bit is a (cycles / bit), according to [42], the time required for video transcoding T_d can be expressed as follows:

$$T_d = aL_r\left(r_j - r_w\right)/f_0, 0 < w < j \leq g, \tag{28}$$

where f_0 represents the server CPU frequency, L_r indicates the length of time that the video segment can support playback, r_j and r_w represent the bit rate in the unit time of playing version j video segment and version w video segment respectively. According to [43], the energy consumption of video transcoding can be expressed as the following equation:

$$E_t = \delta aL_r\left(r_j - r_w\right)T_d, \tag{29}$$

where $\delta\left(Watt/GHz\right)$ is the energy efficiency. Therefore, when the unit energy price of video transcoding consumption is ϕ_t, the video transcoding consumption can be expressed as the following equation:

$$C_t = \phi_t E_t. \tag{30}$$

Similarly, the video transcoding gain G_t is defined as the benefit of the backhaul saved by the user acquiring the required video segments through transcoding in unit time, the backhaul gain G_b is defined as the benefit of the user acquiring the required video segments through the backhaul in unit time, the caching gain G_c^g is defined as the benefit of the backhaul saved by the user acquiring the required video segments through caching in unit time, and the caching consumption G_c^c is defined as the caching resources consumed by users to obtain the required video segments through caching. G_t, G_b, G_c^g and G_c^c can be expressed as follows:

$$G_t = \phi_b P_{V_{tot}}\left(l\right)\bar{C}\left(n\right), \tag{31}$$

$$G_b = \phi_b \bar{C}\left(n\right), \tag{32}$$

$$G_c^g = \phi_b P_{V_{tot}}\left(l\right)\bar{C}\left(n\right), \tag{33}$$

$$G_c^c = \phi_c P_{V_{tot}}\left(l\right)S_{r_k}^{size}\left(i\right), \tag{34}$$

where ϕ_b and ϕ_c represent the unit price of backhaul link and caching respectively.

IV. PROBLEM FORMULATION AND SOLUTION

The objective function can be regarded as the sum of backhaul links gain, caching gain,caching consumption and video transcoding consumption. Here, the objective function can be expressed as the following equation:

$$J_{r_k,i} = \Psi_{r_k}^b\left(i\right)G_b + \Psi_{r_k}^c\left(i\right)\left(G_c^g - G_c^c\right) + \Psi_{r_k}^t\left(i\right)\left(G_t - C_t\right). \tag{35}$$

In order to maximize the benefits of network operators and improve the utilization of network resources, the optimization problem is modeled as the following equation:

$$\begin{aligned} Problem1:\ & maxJ_{r_k,i} \\ s.t.C1:\ & \Psi_{r_k}^c\left(i\right) + \Psi_{r_k}^t\left(i\right) + \Psi_{r_k}^b\left(i\right) = 1, \forall i \in S_{r_k}\left(i\right) \\ C2:\ & \Psi_{r_k}^c\left(i\right)S_{r_k}^{size}\left(i\right) \leq S_c, \forall i \in S_{r_k}\left(i\right) \\ C3:\ & \Psi_{r_k}^b\left(i\right)B \leq B_{ev}, \forall i \in S_{r_k}\left(i\right) \\ C4:\ & \Psi_{r_k}^t\left(i\right)T_d \leq T_k, \forall i \in S_{r_k}\left(i\right) \end{aligned} \tag{36}$$

where S_c, B_{ev} and T_k represent the maximum base station caching, the maximum bandwidth allocated to each vehicle user and the maximum transcoding delay of base station respectively. C1 means that the vehicle user obtains video segment only from one of the schemes of backhaul link, caching and video transcoding. C2, C3 and C4 respectively indicate that the size of the caching video segment does not exceed the available caching size of the base station, the bandwidth required by the vehicle user does not exceed the bandwidth allocated to the vehicle user by the base station, and the video segment size required by the vehicle user for video transcoding does not exceed the transcoding capacity of the base station.

The above problem is obviously a non-convex problem. In order to solve this non-convex problem, the parameters $\Psi_{r_k}^b\left(i\right)$, $\Psi_{r_k}^c\left(i\right)$ and $\Psi_{r_k}^t\left(i\right)$ are relaxed, which can be expressed as $0 \leq \Psi_{r_k}^b\left(i\right) \leq 0$, $0 \leq \Psi_{r_k}^c\left(i\right) \leq 0$ and $0 \leq \Psi_{r_k}^t\left(i\right) \leq 0$ respectively. When the three parameters are interpreted as time fractions, the method of relaxing the three parameters is reasonable. At the same time, the following equation can be obtained from $C1$:

$$\Psi_{r_k}^b\left(i\right) = 1 - \Psi_{r_k}^c\left(i\right) - \Psi_{r_k}^t\left(i\right). \tag{37}$$

Therefore, the objective function can be transformed into the following equation:

$$\begin{aligned} Problem1:\ & maxJ_{r_k,i}\left(\Psi_{r_k}^c\left(i\right), \Psi_{r_k}^t\left(i\right)\right) \\ s.t.C2:\ & \Psi_{r_k}^c\left(i\right)S_{r_k}^{size}\left(i\right) \leq S_c, \forall i \in S_{r_k}\left(i\right) \\ C'3:\ & \left(1 - \Psi_{r_k}^c\left(i\right) - \Psi_{r_k}^t\left(i\right)\right)B \leq B_{ev}, \forall i \in S_{r_k}\left(i\right) \\ C4:\ & \Psi_{r_k}^t\left(i\right)T_d \leq T_k, \forall i \in S_{r_k}\left(i\right) \\ C5:\ & 0 \leq \Psi_{r_k}^c\left(i\right) \leq 1 \\ C6:\ & 0 \leq \Psi_{r_k}^t\left(i\right) \leq 1 \end{aligned} \tag{38}$$

Obviously, the above problem becomes a convex problem, and the optimization results can be obtained through the convex optimization toolbox. After getting the solution of the problem, the solution of the original problem can be obtained by rounding.

V. PRICING ALGORITHM AND CACHING UPDATE ALGORITHM

In order to improve the utilization efficiency of network resources and reduce the operation cost of network operators. In this paper, a dynamic pricing algorithm is proposed based on the idea of grouping evaluation model in [44].

Algorithm 1 Pricing Algorithm

```
**Input:** $\phi_o = \{\phi_{t,o}, \phi_{b,o}, \phi_{c,o}\}$, $\gamma = \{\gamma_t, \gamma_b, \gamma_c\}$ and $\tau = \{\tau_t, \tau_b, \tau_c\}$.
**Output:** $\phi = \{\phi_t, \phi_b, \phi_c\}$.
Initialization;
**while** When vehicle users' demand for network resources changes **do**
Pricing function: $\phi = e^{\gamma+\phi_o*\tau} - 1$;
According to the demand of network resources, $\gamma = \{\gamma_t, \gamma_b, \gamma_c\}$ and $\tau = \{\tau_t, \tau_b, \tau_c\}$ values are given;
Calculate $\phi_t$, $\phi_b$ and $\phi_c$ respectively;
By optimizing the objective function, the utilization of transcoding, backhaul link and caching network resources is adjusted;
break;
**endwhile**;
return $\phi = \{\phi_t, \phi_b, \phi_c\}$;
```

The pricing algorithm can dynamically adjust the price of network resources according to the use of network resources, so as to flexibly allocate network resources for vehicle users. In the pricing algorithm, suppose $\phi_o = \{\phi_{t,o}, \phi_{b,o}, \phi_{c,o}\}$ represents the unit price of video transcoding power consumption, unit price of caching and unit price of backhaul link obtained after the last pricing, and $\phi = \{\phi_t, \phi_b, \phi_c\}$ represents the unit price of video transcoding power consumption, unit price of caching and unit price of backhaul link. $\gamma = \{\gamma_t, \gamma_b, \gamma_c\}$ and $\tau = \{\tau_t, \tau_b, \tau_c\}$ represent the demand and elasticity parameters of ϕ, respectively. Then the pricing algorithm can be expressed as the following equation:

$$\phi = e^{\gamma+\phi_o*\tau} - 1. \tag{39}$$

In the pricing algorithm, network providers can adjust the usage of network resources by adjusting the unit price of caching, transcoding and backhaul links. When the usage of network resources changes, the network provider can adjust the unit price of network resources according to Eq. (39). In the process of adjusting the unit price of network resources, the unit price of network resources is changed mainly by adjusting the demand parameters and elasticity parameters of network resources. The value of demand parameters and elasticity parameters should be adjusted according to the actual demand or according to the historical data. For example, When ϕ is the unit price of the backhaul link, when the backhaul link is congested, both γ and τ become smaller, and the pricing function of the backhaul link becomes smaller. At this time, vehicle users will try to obtain video segment from other ways; When ϕ is the unit price of the backhaul link, when the backhaul link is idle, both γ and τ become larger, and the pricing function of the backhaul link is increased to a certain value, the user will reduce the video transcoding price to reduce the power consumption, so that the user can obtain video resources from the caching or backhaul link. Generally, under different network scenarios, different user needs and different external conditions, the values of parameter values γ, τ and ϕ are different. The pricing algorithm proposed in this paper is one of the solutions to improve the efficiency of network resource utilization. If we want to obtain the parameter values of γ, τ and ϕ under certain scenarios, user needs and external conditions. It needs to be realized through big data processing and machine learning, which will be a huge workload. This will also be the problem we will continue to study in this field. Therefore, this paper only gives a general solution. The detailed pricing algorithm process is shown in algorithm 1.

Algorithm 2 Caching Update Algorithm

```
**Input:** All video segments in caching.
**Output:** Update results of video segments.
Initialization;
According to Zipf law, the top $\iota$ video segments are cached in the base station caching;
The $G_c^g$ values of $\iota$ video segments in the caching are sorted in descending order;
When there are different versions of the same video segment in the caching $\{r_1, r_2, \cdots, r_\kappa\}$, calculates the price $G_t(m,j), 1 \le m < j \le \kappa$ of transcoding from version $m$ to version $j$;
The video transcoding price is calculated for all video segments of different versions of the same video segments in the caching;
The transcoding price of all video segments in the caching and the value $G_c^g$ of all video segments ranks in descending order $rank\{G_t(m,j), G_c^g\}$;
**while** When the popularity ranking of video segments changes **do**
**if** There are new video segments with $G_c^g$ value greater than $\min\{rank\{G_t(m,j), G_c^g\}\}$ && When the size of the new video segment is less than or equal to the size of the $\min\{rank\{G_t(m,j), G_c^g\}\}$ video segment in the caching **then**
    This new video segment directly replaces the video segment of $\min\{rank\{G_t(m,j), G_c^g\}\}$ in caching;
    **else** When the new video segment size $>$ $\min\{rank\{G_t(m,j), G_c^g\}\}$ video segment in caching;
    **if** The sum of caching space required by several video segments of $\min\{rank\{G_t(m,j), G_c^g\}\}$ in caching $>=$ the size of new video segments, and the total price of these video segments $<=$ $G_c^g$ of new video segments **then**
        The new video segment replaces the least expensive video segments in the caching;
        **else** Caching does not update;
        break;
    **end if**
**end if**
return result;
```

Since the caching space is not infinite, a caching strategy is needed to determine which video segments need to be cached. In the caching update algorithm proposed in this paper, firstly, the video segments are cached according to the popularity. When the caching space is not enough to support a new video segment caching, and if the popularity of video segments changes at this time, it is necessary to consider which video segments in the caching space are updated first. Different from the existing caching update schemes, the caching update algorithm proposed in this paper caches video segments according to the value of video segments. When there are different versions of the same video segment in the caching, it is not accurate to update the caching only considering the popularity of the video segment. The proposed caching update algorithm not only considers the caching value brought by the popularity of video segments, but also considers the transcoding value of video segments. The caching value and transcoding value of the video segments in the caching are sorted in descending order. When the value of a new video segment caching is greater than the current minimum value of the video segment in the caching, the caching will execute the caching update algorithm proposed in this paper to determine whether to execute the caching update. In the caching update algorithm, the transcoding value of video segment is taken into account, which can improve the utilization of caching. The detailed algorithm is shown in algorithm 2.

TABLE 2. Simulation parameters.

Simulation parameters	Value
Transmission power of the base station	P= 1w
Noise power density	I= -174dbm/Hz
The density of base stations	λ_s =70/1000$^2\pi$
Server CPU frequency	f_0= 3.4 × 10^{9}Hz
Time spent by user handover BS each time	H_t= 0.3s
Path loss index	η_{fem}= 4
Base station available caching size	S_c= 40Mb
Bandwidth allocated to each vehicle user	B_{ev}= 1Mbps
Size of video segment	$S_{r_k}^{size}(i)$= 2Mb

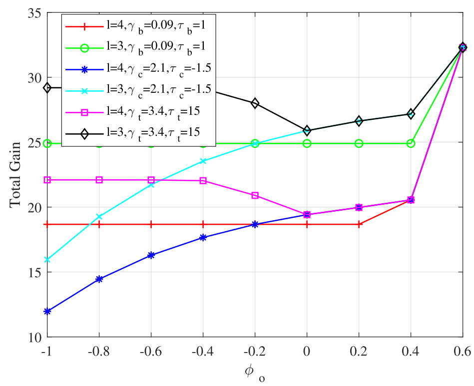

FIGURE 3. Performance analysis of pricing algorithm.

VI. SIMULATION RESULTS AND DISCUSSIONS

In this section, we will implement the algorithm through simulation to verify the effectiveness of the proposed scheme. In the simulation process, the values of corresponding parameters can be set according to [37]. The detailed parameter values are given in Table 2.

For the convenience of analysis, the demand parameter γ and elasticity parameter τ in Fig. 3 are assumed to be constant values (if the demand parameter γ and elasticity parameter τ take any value within a reasonable range, different curves will be obtained). Fig. 3 shows that when the demand parameters and elasticity parameters remain unchanged, the higher the video segment popularity ranking, the more the total gain. This is mainly due to the higher the ranking video segment, the more the probability of vehicle users requesting the video segment, which increases the total gain of the video segment. When only the price of backhaul link changes, the total gain is a constant value for a long time. This is mainly because the vehicle users get the video segments from the caching or transcoding scheme. When the total gain rises later, it means that the vehicle users can get the video segments from the backhaul link to maximize the total gain. When only caching price changes. From the simulation results, we can see that when $\phi_o \leq 0$, the vehicle users get the video segments from the caching to maximize the total gain; when $0 \leq \phi_o \leq 0.4$, the vehicle users get the video segments from the video transcoding to maximize the total gain; when $0.4 \leq \phi_o$, the vehicle users get the video segments from the backhaul link to maximize the total gain. In the process of only video transcoding price changes. We can see that when $\phi_o \leq -0.4$, the vehicle users can obtain the required video segments from the video transcoding to maximize the total gain; when $-0.4 \leq \phi_o \leq 0$, the vehicle users can get the video segments from the combination scheme of video transcoding and caching to maximize the total gain; when $0 \leq \phi_o \leq 0.4$, the vehicle users can get the video segments from the caching to maximize the total gain; when $0.4 \leq \phi_o$, the vehicle users can get the video segment from the backhaul link to maximize the total gain.

Fig. 4 illustrates the relationship between pure gain and video popularity. Applying this relationship to caching update scheme can improve the utilization of caching space. Obviously, the pure gain of both caching scheme and video transcoding scheme decreases with the increase of video segment popularity l. The main reason for this result is that the higher the popularity l value is, the less popular the video segment is, and the less likely the vehicle user requests to obtain the video segment, which makes the pure gain be reduced. In the caching scheme, when the popularity of video segments is the same, the pure gain decreases with the increase of video segment size, which is mainly due to the limited caching space of the base station. Similarly, in the video transcoding scheme, when the popularity of video segments is the same, the pure gain decreases with the increase of video segment size, which is mainly due to the limitation of the computing ability of the base station. When the video segment size is 2Mb, the caching pure gain value is equal to the video

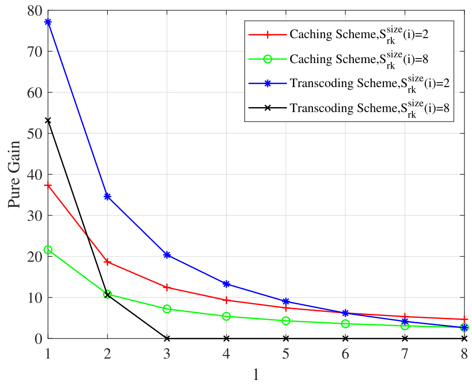

FIGURE 4. The relationship between pure gain and video popularity.

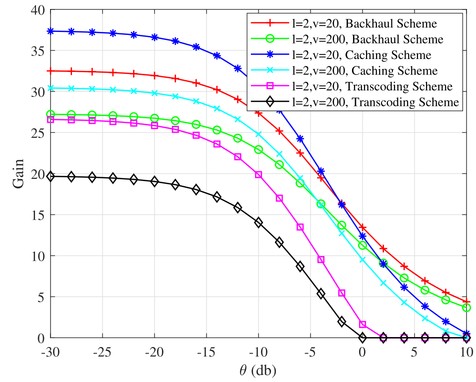

FIGURE 6. Relationship between gain and handover threshold of vehicle users.

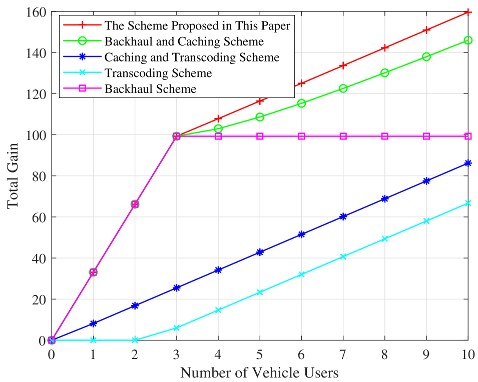

FIGURE 5. Relationship between total gain and number of vehicle users.

transcoding pure gain value at $l = 6$. At this time, when updating the caching, we need to fully consider the impact of video transcoding gain on caching gain, so as to improve the utilization efficiency of caching.

The results in Fig. 5 describe the relationship between total gain and number of vehicle users. It can be seen from the results that the total gain of all schemes will increase with the increase of the number of vehicle users. However, when the number of vehicle users is more than 3, the proposed scheme can significantly improve the total gain. The main reason for this result is that vehicle users can flexibly obtain the required video segments from three ways, which including backhaul link, caching and video transcoding. When the vehicle users obtain the video segments through the backhaul link and caching scheme, the total gain of the vehicle users will be smaller than that of the scheme proposed in this paper. The main reason for this result is that because the vehicle users can only get the required video segments from the backhaul link and caching. In the absence of video transcoding scheme, the flexibility of vehicle users to obtain the required video segments is reduced, so the total revenue is reduced. At the same way, when the vehicle user obtains the required video segments from the caching and transcoding scheme, the total gain decreases due to the reduced flexibility of the vehicle user to obtain the required video segments. In the scheme in which the vehicle user obtains the desired video segments from the backhaul link. When the number of vehicle users is less than 3, the total gain increases with the number of vehicle users; when the number of vehicle users exceeds 3, the total gain does not change with the increase of the number of vehicle users. The main reason for this result is that the bandwidth allocated to each base station is limited. In the scheme that the vehicle user obtains the required video segments from video transcoding. When the number of vehicle users is less than 2, the total gain is 0. This is mainly because the video segments needed by video transcoding need to consume a certain amount of caching resources, which makes the video transcoding revenue offset the caching consumption. When the number of vehicle users is greater than 2, the total gain increases with the increase of vehicle users.

Fig. 6 shows the relationship between the gain and the vehicle user handover threshold. It can be seen from the simulation results that the gain decreases with the increase of the handover threshold. The main reason for this result is that the base station becomes more and more difficult to meet the needs of vehicle users with the increase of handover threshold. Among all the video acquisition schemes, when the vehicle users' speed is equall, the caching scheme obtains the largest gain, followed by the backhaul link scheme, and the video transcoding scheme obtains the smallest gain. The main reason for this result is the influence of pricing mechanism and the handover of base station by vehicle users. In the backhaul link scheme, the gain will decrease with the increase of vehicle user's speed. The main reason for this result is that with the increase of vehicle user speed, the number of handover in unit time will increase, which will reduce the gain. In the same way, in the caching scheme and video transcoding scheme, with the increase of the speed of vehicle users, the gain will decrease.

Compared with Fig. 6 and Fig. 7, it can be seen that with the increase of video segment popularity ranking, the gain will decrease when the vehicle user speed is the constant and the scheme to obtain the required video segment is the same. However, the influence of the popularity of video segments on different video obtain schemes is different. In the backhaul link scheme, with the increase of video segment popularity,

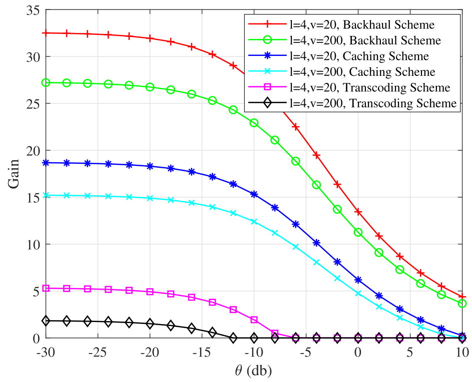

FIGURE 7. Relationship between gain and handover threshold of vehicle users.

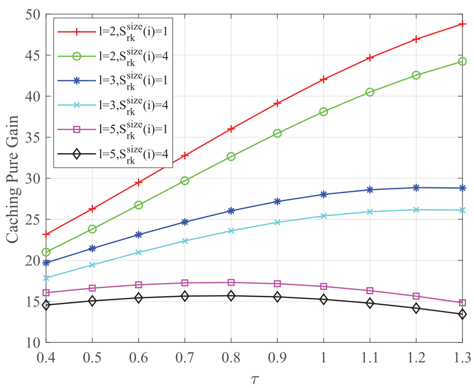

FIGURE 8. The relationship between caching pure gain and τ.

the total gain is basically not affected. This is mainly because in the backhaul link scheme, the gain is only related to the data transmission rate. Video segment popularity has a great impact on the gain of caching scheme and video transcoding scheme. In these two schemes, the gain will decrease with the increase of video segment popularity. The main reason for this result is that the caching consumption and transcoding consumption of the video segment remain unchanged. However, with the increase of the popularity of the video segment, the probability of vehicle users to request the video segment decreases, resulting in the decrease of the gain. At the same time, the numerical comparison on the curve in the simulation results shows that the video segment popularity has the greatest impact on the gain of transcoding scheme.

Fig. 8 shows the relationship between caching pure gain and τ. Obviously, when the other conditions are same, the caching pure gain will decrease with the increase of the size of video segments. This is mainly due to the fact that the number of video segments stored in the caching space will be reduced when the size of the available caching space is limited, and the hit rate of video segments requested by vehicle users will be reduced, thus the pure gain of caching will be reduced. When the popularity ranks of a video segment are $l = 2$, the pure gain of caching increases with the increase of τ value. When the popularity ranks of a video segment are $l = 3$, the pure

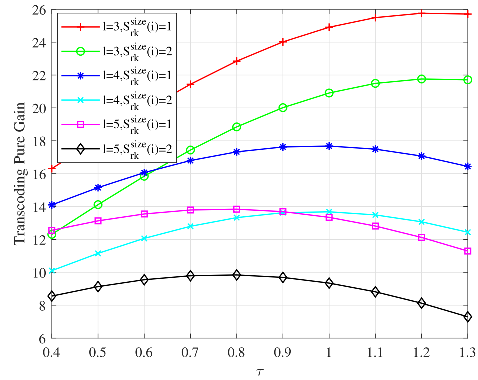

FIGURE 9. The relationship between transcoding pure gain and τ.

gain of caching increases with the increase of τ value, but when $1 \leq \tau$, the increase speed of caching pure gain slows down. When the popularity ranks of a video segment are $l = 5$, the pure gain of caching increases with the increase of τ value, but when $1.1 \leq \tau$, the pure gain of caching decreases with the increase of τ value. The main reason for this result is that the τ value is different when the Zipf law is applied to different contents. Therefore, in practical application, a reasonable τ value should be selected according to the actual needs.

Fig. 9 shows the relationship between the pure gain of video transcoding and τ. We can see that when the other conditions are the same, the pure gain of transcoding will decrease with the increase of video segment size. The main reason for this result is that the transcoding capacity of the base station is limited, and the increase of video segment size will reduce the number of transcoding video segments per unit time. The number of service vehicle users is reduced, and the pure gain of transcoding is reduced. When the popularity ranks of a video segment are $l = 3$, the pure gain of transcoding increases with the increase of τ. When the popularity ranks of a video segment are $l = 4$, the pure gain of transcoding increased with the increase of τ, but when $1 \leq \tau$, the pure gain of transcoding decreased with the increase of τ value. When the popularity ranks of a video segment are $l = 5$, the pure gain of transcoding increases with the increase of τ value, but when $0.8 \leq \tau$, the pure gain of transcoding decreases with the increase of τ value. The main reason for this result is that different τ values are needed when Zipf's law is applied to different contents.

VII. CONCLUSION

In this paper, the author focuses on the problem that vehicle users obtain video services in different ways. In the process of scene analysis, considering the randomness of base station distribution, the mobility of vehicle users and the probability of vehicle user handover in the actual scene, a data transmission rate analysis scheme based on stochastic geometry theory is proposed to improve the accuracy of the analysis process. In the process of vehicle users acquiring the required video segments, it is considered that the use status of network resources is different when vehicle users make video requests at different times. A pricing algorithm that can improve the flexibility of network resources such as caching, base station computing resources and backhaul link is proposed. At the same time, the caching update algorithm proposed in this paper takes video transcoding gain fully into account in the update of caching space, which can effectively improve the efficiency of caching. From the simulation results, it can be seen that the vehicle video segment acquisition scheme proposed in this paper can improve the efficiency of network resources.

REFERENCES

[1] C. Liu, H. Zhang, H. Ji, and X. Li, "MEC-assisted flexible transcoding strategy for adaptive bitrate video streaming in small cell networks," *China Commun.*, vol. 18, no. 2, pp. 200–214, Feb. 2021.

[2] Y. Zhou, J. Chen, G. Ye, D. Wu, J. H. Wang, and M. Chen, "Collaboratively replicating encoded content on RSUs to enhance video services for vehicles," *IEEE Trans. Mobile Comput.*, vol. 20, no. 3, pp. 877–892, Mar. 2021.

[3] J. Liu, M. Ahmed, M. A. Mirza, W. U. Khan, D. Xu, J. Li, A. Aziz, and Z. Han, "RL/DRL meets vehicular task offloading using edge and vehicular cloudlet: A survey," *IEEE Internet Things J.*, vol. 9, no. 11, pp. 8315–8338, Jun. 2022.

[4] A. Masood, D. S. Lakew, and S. Cho, "Security and privacy challenges in connected vehicular cloud computing," *IEEE Commun. Surveys Tuts.*, vol. 22, no. 4, pp. 2725–2764, 4th Quart., 2020.

[5] L. Wang, H. Yang, X. Qi, J. Xu, and K. Wu, "iCast: Fine-grained wireless video streaming over internet of intelligent vehicles," *IEEE Internet Things J.*, vol. 6, no. 1, pp. 111–123, Feb. 2019.

[6] H. Liu, P. Wang, J. Lin, H. Ding, H. Chen, and F. Xu, "Real-time longitudinal and lateral state estimation of preceding vehicle based on moving horizon estimation," *IEEE Trans. Veh. Technol.*, vol. 70, no. 9, pp. 8755–8768, Sep. 2021.

[7] M. Yan, W. Li, C. A. Chan, S. Bian, I. Chih-Lin, and A. F. Gygax, "PECS: Towards personalized edge caching for future service-centric networks," *China Commun.*, vol. 16, no. 8, pp. 93–106, Aug. 2019.

[8] D. López-Pérez, A. De Domenico, N. Piovesan, G. Xinli, H. Bao, S. Qitao, and M. Debbah, "A survey on 5G radio access network energy efficiency: Massive MIMO, lean carrier design, sleep modes, and machine learning," *IEEE Commun. Surveys Tuts.*, vol. 24, no. 1, pp. 653–697, 1st Quart., 2022.

[9] Y. Chen, M. Ding, D. López-Pérez, X. Yao, Z. Lin, and G. Mao, "On the theoretical analysis of network-wide massive MIMO performance and pilot contamination," *IEEE Trans. Wireless Commun.*, vol. 21, no. 2, pp. 1077–1091, Feb. 2022.

[10] J. Huang, F. Yang, Y. Gao, Z. Wang, and J. Zhong, "A pilot contamination avoidance based on pilot pattern design for ultra-dense network," *China Commun.*, vol. 17, no. 12, pp. 235–246, Dec. 2020.

[11] M. Sheraz, M. Ahmed, X. Hou, Y. Li, D. Jin, Z. Han, and T. Jiang, "Artificial intelligence for wireless caching: Schemes, performance, and challenges," *IEEE Commun. Surveys Tuts.*, vol. 23, no. 1, pp. 631–661, 1st Quart., 2021.

[12] B. Jedari, G. Premsankar, G. Illahi, M. D. Francesco, A. Mehrabi, and A. Ylä-Jääski, "Video caching, analytics, and delivery at the wireless edge: A survey and future directions," *IEEE Commun. Surveys Tuts.*, vol. 23, no. 1, pp. 431–471, 1st Quart., 2021.

[13] H. S. Goian, O. Y. Al-Jarrah, S. Muhaidat, Y. Al-Hammadi, P. Yoo, and M. Dianati, "Popularity-based video caching techniques for cache-enabled networks: A survey," *IEEE Access*, vol. 7, pp. 27699–27719, 2019.

[14] X. Jiang, F. R. Yu, T. Song, and V. C. M. Leung, "A survey on multi-access edge computing applied to video streaming: Some research issues and challenges," *IEEE Commun. Surveys Tuts.*, vol. 23, no. 2, pp. 871–903, 2nd Quart., 2021.

[15] J. Luo, F. R. Yu, Q. Chen, and L. Tang, "Adaptive video streaming with edge caching and video transcoding over software-defined mobile networks: A deep reinforcement learning approach," *IEEE Trans. Wireless Commun.*, vol. 19, no. 3, pp. 1577–1592, Mar. 2020.

[16] J. Yoon and S. Banerjee, "Hardware-assisted, low-cost video transcoding solution in wireless networks," *IEEE Trans. Mobile Comput.*, vol. 19, no. 3, pp. 581–597, Mar. 2020.

[17] W. Zhang, H. Sun, D. Zhao, L. Xu, X. Liu, H. Ning, J. Zhou, Y. Guo, and S. Yang, "A streaming cloud platform for real-time video processing on embedded devices," *IEEE Trans. Cloud Comput.*, vol. 9, no. 3, pp. 868–880, Jul. 2021.

[18] L. Costero, A. Iranfar, M. Zapater, F. D. Igual, K. Olcoz, and D. Atienza, "Resource management for power-constrained HEVC transcoding using reinforcement learning," *IEEE Trans. Parallel Distrib. Syst.*, vol. 31, no. 12, pp. 2834–2850, Dec. 2020.

[19] Y. Guo, F. R. Yu, J. An, K. Yang, C. Yu, and V. C. M. Leung, "Adaptive bitrate streaming in wireless networks with transcoding at network edge using deep reinforcement learning," *IEEE Trans. Veh. Technol.*, vol. 69, no. 4, pp. 3879–3892, Apr. 2020.

[20] L. Li, G. Zhao, and R. S. Blum, "A survey of caching techniques in cellular networks: Research issues and challenges in content placement and delivery strategies," *IEEE Commun. Surveys Tuts.*, vol. 20, no. 3, pp. 1710–1732, 3rd Quart., 2018.

[21] A. M. Ibrahim, A. A. Zewail, and A. Yener, "Device-to-device coded-caching with distinct cache sizes," *IEEE Trans. Commun.*, vol. 68, no. 5, pp. 2748–2762, May 2020.

[22] Y. Lin, Z. Lin, P. Chen, Z. Chen, and L. Wu, "On consideration of content and memory sizes in 5G D2D-assisted caching networks," *IEEE Access*, vol. 8, pp. 52759–52773, 2020.

[23] T.-V. Nguyen, N.-N. Dao, V. D. Tuong, W. Noh, and S. Cho, "User-aware and flexible proactive caching using LSTM and ensemble learning in IoT-MEC networks," *IEEE Internet Things J.*, vol. 9, no. 5, pp. 3251–3269, Mar. 2022.

[24] X. Zhang, Y. Zhou, D. Wu, M. Hu, X. Zheng, M. Chen, and S. Guo, "Optimizing video caching at the edge: A hybrid multi-point process approach," *IEEE Trans. Parallel Distrib. Syst.*, vol. 33, no. 10, pp. 2597–2611, Oct. 2022.

[25] C. Bhar and E. Agrell, "Energy- and bandwidth-efficient, QoS-aware edge caching in fog-enhanced radio access networks," *IEEE J. Sel. Areas Commun.*, vol. 39, no. 9, pp. 2762–2771, Sep. 2021.

[26] H. Liao, G. Tang, D. Guo, K. Wu, and Y. Wu, "EdgeSaver: Edge-assisted energy-aware mobile video streaming for user retention enhancement," *IEEE Internet Things J.*, vol. 9, no. 9, pp. 6550–6562, May 2022.

[27] C. Wang, D. Feng, S. Zhang, and Q. Chen, "Video caching and transcoding in wireless cellular networks with mobile edge computing: A robust approach," *IEEE Trans. Veh. Technol.*, vol. 69, no. 8, pp. 9234–9238, Aug. 2020.

[28] H. Zhao, Q. Zheng, W. Zhang, and J. Wang, "Prediction-based and locality-aware task scheduling for parallelizing video transcoding over heterogeneous mapreduce cluster," *IEEE Trans. Circuits Syst. Video Technol.*, vol. 28, no. 4, pp. 1009–1020, Apr. 2018.

[29] E. Baccour, F. Haouari, A. Erbad, A. Mohamed, K. Bilal, M. Guizani, and M. Hamdi, "An intelligent resource reservation for crowdsourced live video streaming applications in geo-distributed cloud environment," *IEEE Syst. J.*, vol. 16, no. 1, pp. 240–251, Mar. 2022.

[30] Y. Liu, F. R. Yu, X. Li, H. Ji, and V. C. M. Leung, "Decentralized resource allocation for video transcoding and delivery in blockchain-based system with mobile edge computing," *IEEE Trans. Veh. Technol.*, vol. 68, no. 11, pp. 11169–11185, Nov. 2019.

[31] X. Chen, C. Xu, M. Wang, Z. Wu, L. Zhong, and L. A. Grieco, "Augmented queue-based transmission and transcoding optimization for livecast services based on cloud-edge-crowd integration," *IEEE Trans. Circuits Syst. Video Technol.*, vol. 31, no. 11, pp. 4470–4484, Nov. 2021.

[32] Y. Ming, J. Chen, Y. Dong, and Z. Wang, "Evolutionary game based strategy selection for hybrid V2V communications," *IEEE Trans. Veh. Technol.*, vol. 71, no. 2, pp. 2128–2133, Feb. 2022.

[33] H. Liang, X. Zhang, X. Hong, Z. Zhang, M. Li, G. Hu, and F. Hou, "Reinforcement learning enabled dynamic resource allocation in the internet of vehicles," *IEEE Trans. Ind. Informat.*, vol. 17, no. 7, pp. 4957–4967, Jul. 2021.

[34] X. Hong, J. Jiao, A. Peng, J. Shi, and C.-X. Wang, "Cost optimization for on-demand content streaming in IoV networks with two service tiers," *IEEE Internet Things J.*, vol. 6, no. 1, pp. 38–49, Feb. 2019.

[35] P. Maniotis and N. Thomos, "Tile-based edge caching for 360° live video streaming," *IEEE Trans. Circuits Syst. Video Technol.*, vol. 31, no. 12, pp. 4938–4950, Dec. 2021.

[36] X. Huang, L. He, L. Wang, and F. Li, ''Towards 5G: Joint optimization of video segment caching, transcoding and resource allocation for adaptive video streaming in a multi-access edge computing network,'' *IEEE Trans. Veh. Technol.*, vol. 70, no. 10, pp. 10909–10924, Oct. 2021.
[37] R. Arshad, H. ElSawy, S. Sorour, T. Y. Al-Naffouri, and M.-S. Alouini, ''Velocity-aware handover management in two-tier cellular networks,'' *IEEE Trans. Wireless Commun.*, vol. 16, no. 3, pp. 1851–1867, Mar. 2017.
[38] Y. Zhou, F. R. Yu, J. Chen, and Y. Kuo, ''Video transcoding, caching, and multicast for heterogeneous networks over wireless network virtualization,'' *IEEE Commun. Lett.*, vol. 22, no. 1, pp. 141–144, Jan. 2018.
[39] W. Bao and B. Liang, ''Stochastic geometric analysis of user mobility in heterogeneous wireless networks,'' *IEEE J. Sel. Areas Commun.*, vol. 33, no. 10, pp. 2212–2225, Oct. 2015.
[40] J. G. Andrews, F. Baccelli, and R. K. Ganti, ''A tractable approach to coverage and rate in cellular networks,'' *IEEE Trans. Commun.*, vol. 59, no. 11, pp. 3122–3134, Nov. 2011.
[41] R. Arshad, H. ElSawy, S. Sorour, T. Y. Al-Naffouri, and M.-S. Alouini, ''Handover management in dense cellular networks: A stochastic geometry approach,'' in *Proc. IEEE Int. Conf. Commun. (ICC)*, May 2016, pp. 1–7.
[42] Z. Li, R. Xie, Q. Jia, and T. Huang, ''Energy-efficient joint caching and transcoding for HTTP adaptive streaming in 5G networks with mobile edge computing,'' in *Proc. IEEE Int. Conf. Commun. Workshops (ICC Workshops)*, May 2018, pp. 1–6.
[43] K. Zhang, Y. Mao, S. Leng, Q. Zhao, L. Li, X. Peng, L. Pan, S. Maharjan, and Y. Zhang, ''Energy-efficient offloading for mobile edge computing in 5G heterogeneous networks,'' *IEEE Access*, vol. 4, pp. 5896–5907, 2016.
[44] Y. Liu, X. Li, F. R. Yu, H. Ji, H. Zhang, and V. C. M. Leung, ''Grouping and cooperating among access points in user-centric ultra-dense networks with non-orthogonal multiple access,'' *IEEE J. Sel. Areas Commun.*, vol. 35, no. 10, pp. 2295–2311, Oct. 2017.

WENBIN FU received the M.E. degree majoring in signal and information processing from Shandong Normal University (SNU), China, in 2014. He is currently pursuing the Ph.D. degree with the School of Information and Communication Engineering, Beijing University of Posts and Telecommunications (BUPT), China. His current research interests include radio resource management, mobility analysis, and MIMO technology in wireless communications and networks.