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Mobile Edge Computing to Assist the Online Ideological and Political Education

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ABSTRACT

With the rapid development of mobile internet technology, mobile network data traffic presents an explosive growth trend. Especially, the proportion of mobile video business has become a large proportion in mobile internet business. Mobile video business is considered as a typical business in the 5G network, such as in online education. The growth of video traffic poses a great challenge to mobile network. In order to provide users with better quality of experience (QoE), it requires mobile network to provide higher data transmission rate and lower network delay. This paper adopts a combined optimization to minimize total cost and maximize QoE simultaneously. The optimization problem is solved by ant colony algorithm. The effectiveness is verified on experiment.

KEYWORDS

Mobile Edge Computing, Online Education, Video Caching Strategy

1. INTRODUCTION

With the development of mobile Internet and Internet of things (IoT) (Srinivasan et al. 2019), mobile HD video (Usman et al. 2018), augmented reality and virtual reality (AR/VR) (Nayyar et al. 2018), and various intelligent hardware devices (Liu et al. 2019; Zhang 2020) have become an indispensable part of people's life. These network technologies and applications do not only enrich people's lives, but also generate huge mobile network traffic.

The rapid growth of mobile network traffic (Yan 2019), especially mobile video traffic, has brought great pressure and challenges to the mobile network. The traffic explosion has brought the following impacts on the current mobile network. First, the pressure of backhaul network and mobile core network is huge. The rapid growth of mobile network traffic makes the pressure of mobile backhaul network increase, the bandwidth resource be tight, and the load of mobile core network is serious. Second, the repeated transmission of content induces in a great waste of network resources. At present, the end-to-end transmission mechanism (Sun et al. 2017) in mobile network will cause the repeated transmission of a large number of popular content, especially the transmission of mobile high-definition video content. Third, the network delay is large which induces bad user experience. In the current mobile network, the user's content request must pass through the base station, S-GW, P-GW to enter the Internet (Zhou et al. 2020). The content is routed to the content server. The spatial distance between the user and the content server (Charu et al. 2017) makes the network transmission delay be larger. In addition, the quality of user experience is influenced on the processing delay of the

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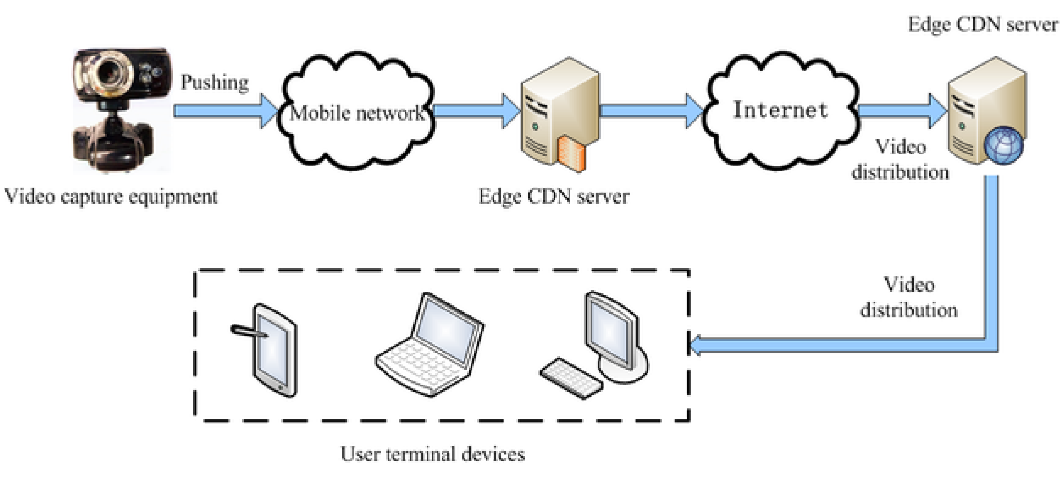
content server, the congestion and packet loss of the transmission link, link failure and other special circumstances (Medeiros et al. 2019).

In order to cope with the explosion of mobile network traffic, improve the quality of users' network experience, accelerate the efficiency of content distribution, and alleviate the transmission pressure of backhaul network, multi access edge computing (Pham et al. 2020) is proposed. It aims to provide end users with ultra-low latency and high bandwidth services through cloud computing capability and service environment for content providers and application developers at the edge of mobile network.

At the same time, the webcast has become an important network application (Na and Jahng 2019). Webcast refers to the process that the audio and video signals are compressed and uploaded to the web server or multimedia server, and distributed on the Internet according to the user's request. In recent years, with the rapid development of the Internet, the webcast has emerged in real life and become popular among mobile users. The current live broadcast services (Wang et al. 2018) include sports events, concerts, remote meetings, online education etc. However, there are still many problems in the current network video live broadcasting system, such as poor mobility, large delay, video jam, difficult to guarantee quality of service.

With the development of MEC technology, video distribution scheme based on MEC has become an important method to improve the quality of webcast. This paper adopts MEC to aid online ideological and political education. The architecture is illustrated in the following figure.

Figure 1. The architecture of MEC based webcast to assist online ideological and political education



2. PROBLEM DESCRIPTION AND PREVIOUS WORK

The content delivery network (CDN) based live video distribution is the mainstream live video distribution scheme (Retal et al. 2017; Viola et al. 2018). The video capture device pushes the collected and recorded video stream to the edge CDN server node which is responsible for caching and transcoding the live video stream. The video stream is distributed to the delivery network server through the Internet or content delivery network to provide live video service for users. In the aspect of mobility, because the edge CDN server is deployed outside the mobile network, when the video capture device is connected to the network through mobile mode, it needs to go through the mobile access network and the core network to access to the CDN server at the edge of the Internet. Thus, it will bring a certain network delay and affect the user experience. When the edge CDN server is accessed in a fixed way, the mobility of video capture devices will be limited. In addition, the path from the video capture device to the user side edge CDN server is too long and the delay is high. At the same time, the probability of failure on the path is high as well. Thus, the errors are easy to occur. In order to solve this issue, this paper a novel webcast video distribution scheme based on mobile edge computing to assist online ideological and political education.

The live webcast video distribution system based on MEC is composed of video acquisition equipment, base station, MEC server at video source, transmission network, MEC server at user end and user terminal devices. The video capture device first pushes the collected and recorded video to the MEC server. Because MEC has the function of local traffic unloading, MEC can directly push the live video stream to the Internet or distribute the live video stream to the MEC server that is close to the user through the network dedicated line.

Since MEC is generally deployed at the edge of the network close to users in a distributed manner, strengthening the cooperation between distributed MECs is of great significance to improve the efficiency of content distribution. In the cooperative distribution scheme of distributed deployment MEC, there are two connection modes between MECs: through network dedicated line connection and through ordinary Internet connection. The MECs are connected through network dedicated lines, which has higher network bandwidth and can guarantee quality of server (QoS). In the scenario of distributed deployment of MEC, when the video capture device pushes the content to its nearest MEC server, the MEC server immediately synchronizes the content with the MEC server in other locations, and then the terminal device can request the content from the nearest MEC server.

In order to more intuitively describe the proposed webcast video distribution scheme in this paper, we describe the specific distribution process as follows. After the video acquisition device collects the video, it first transmits the video content to the base station through the wireless link, and then the base station directly pushes the video content to the nearest MEC server which caches and transcodes the video pushed by the base station. If the local user requests video content, MEC server can directly respond to the user's request. For non-local users, we introduce the cooperation mechanism of MEC server, that is, the video content on MEC server is synchronized with MEC servers in other places in real time through the network dedicated line or Internet.

Compared with the traditional video distribution scheme, the mobile network live video distribution scheme based on MEC has the following advantages.

- It can ensure video quality. In the traditional scheme, the quality of video content received through web server is affected by uncertainty factors, such as the distance between the video capture device and the web server or CDN server, link congestion and network node failure in the process of video uploading. In the live broadcast scheme based on MEC, the video capture device directly pushes the video content to the MEC server which is deployed at the edge of the network. Thus, it can alleviate this uncertainties in traditional scheme.
- It can reduce transmission delay. In the traditional scheme, the video content needs to be transmitted from the video capture device to the web server or CDN server, and then distributed to the end users in need. However, the long-distance upload from the video capture device to the service server will lead to a relatively large delay. At the same time, the web server or CDN server is not as close to the users as the MEC server. In the MEC based scheme, the MEC server is located at the edge of the network and close to the live video collection device and user. Therefore, the delay of MEC based scheme is lower than that of traditional scheme.
- It implemented link awareness and video online transcoding. In large-scale network video live broadcasting, it requires HD video, such as 4K / 8K HD video. In the traditional scheme, only the video with the highest resolution is transmitted from the video capture device to the web server. For the web server of the content provider, the video is transcoded to the corresponding resolution according to the needs of the user terminal devices. Thus, the traditional scheme does not only require high performance of the web server of the website, but also occupies a large amount of

core network bandwidth. In the MEC based scheme, the MEC server can sense the user link. When it detects that the link of some users is idle, it can recover the link resources and allocate them to other users to transmit high-quality video for users. When it is detected that the user link condition drops, the MEC server can also use its strong data processing or computing power to transcode HD video into video with lower bit rate in real time to meet the needs of end users

The comparison between traditional scheme and MEC based scheme is listed in the following table from the aspects of node number, deployment location, content distribution mode, mobility and distribution path.

Table 1. The comparison between traditional scheme and MEC based scheme

	CDN based scheme	MEC based scheme
Number of nodes	less	more
Deployment location	Deployed in Internet which is far away terminal user	Deployed at the edge of mobile network which is close to terminal user
Content distribution mode	From web server in Internet to terminal users	From video broadcast source to terminal users
Mobility	Less mobility	can support mobility
Distribution path	Fixed network	At the MEC at the edge of the mobile network, it unloads the traffic to the Internet or distribute it through the network dedicated line

3. CACHING STRATEGY FOR VIDEO DISTRIBUTION IN MOBILE EDGE COMPUTING FRAMEWORK

The content caching and transcoding on MEC nodes use the Internet service providers (ISPs) to reduce the cost through reducing the traffic between the return network and ISPs. The video processing at edge nodes can improve the QoE through reduce latency and network congestion at clients.

Let $V = \{V_1,\ldots,V_n\}$ represent video set which can be requested by users. Each video V_i has l version with different bit rate. Then, the video is represented as $V_{i,1},\ldots,V_{i,l}$ in which the items are sorted according to bit rate in ascending order. The $V_{i,1}$ represents the lowest bit rate version, while $V_{i,l}$ represents the highest bit rate version. The $V_{i,j}$ represents the version with the j^{th} bit rate. Let $r_{v_{i,j}}$ represent the j^{th} bit rate of video V_i. Let t_i be the length of video V_i. Then, the size of video $v_{i,j}$ is represented as $s_{v_{i,j}} = t_i * r_{v_{i,j}}$.

The MEC server node has caching and computing capabilities. It cannot only cache different video clips with different bit rate versions, but also realize transcoding between different bit rate versions of the same video clip. In this case, when the request for video segment v_i with bit rate $r_{i,j}$ reaches the MEC server node, there are three possible modes.

- Direct hit mode. When there is a video segment v_i in the MEC server node, the MEC server node will respond directly to the user by delivering the video segment v_i.

- Transcoding hit mode. If the video segment v_i does not exist in the MEC server node and there is a high bit rate version $v_{i,j}$, the transcoding mechanism is triggered. The MEC server node can transcode the high version video segment to the requested bit rate version, or request the original video segment from the source content server through the return link, which depends on the decision of the transcoding scheduling scheme. Generally, the higher bit rate version can be transcoded to the lower bit rate version, but the lower bit rate version cannot be upgraded to the higher bit rate version.
- Miss mode. The MEC server node contains neither the video segment v_i of the requested bit rate version nor the higher bit rate version that is available for transcoding. In the Miss mode, the MEC server node will directly obtain the requested video content from the original server to respond to the user's request.

For each video v_i, we use a binary variable $\{x_{v_{i,l}}, x_{v_{i,h}}, y_{v_{i,l}}, z_{v_{i,l}}, z_{v_{i,h}}\} \in \{0,1\}$ to denote the decision vector when the video request reaches the MEC server node.

The $x_{v_{i,l}}$ is the cache variable to identify whether the video clip with bit rate $r_{i,l}$ has been cached. When $v_{i,l}$ is cached in the MEC server node, $x_{v_{i,l}} = 1$; otherwise, $x_{v_{i,l}} = 0$. Let m represent the maximum of the cache size. The size of video cannot exceed m. The $x_{v_{i,l}}$ satisfies the following condition.

$$\sum_{i=1}^{n} \sum_{j=1}^{l} x_{v_{i,j}} * t * r_{v_{i,j}} \le m \tag{1}$$

The MEC server node can provide computing power to realize transcoding between different bit rate versions of the same video clip. The $x_{v_{i,h}}$ represents whether there exists a video with high bit rate. When there exists high bit rate video, $x_{v_{i,h}} = 1$; otherwise, $x_{v_{i,h}} = 0$. $x_{v_{i,h}}$ can be obtained by the following formula.

$$x_{v_{i,h}} = \min\left\{1, \sum_{j=l+1}^{l} x_{v_{i,j}}\right\} \tag{2}$$

The $y_{v_{i,l}}$ is used to describe the transcoding decision for video $v_{i,l}$. When $y_{v_{i,l}} = 1$, the MEC server node obtains the video through transcoding; otherwise, the video is obtained from source server directly. Because the transcoding can only be performed when the high bit rate version is cached in the MEC server node, the $y_{v_{i,l}} = 1$ is subject to the following constraint.

$$y_{v_{i,l}} \le x_{v_{i,l}} \tag{3}$$

The $z_{v_{i,l}}$ indicates whether the video is obtained from source server, while $z_{v_{i,h}}$ indicates whether the video is obtained from the adjacent MEC server node. It is assumed that the video is obtained from adjacent server with 50%. Then, $z_{v_{i,h}}$ is constrained by the following condition.

$$z_{v_{i,h}} \le \frac{rand\left(\ \right)}{0.5} \tag{2}$$

Since $x_{v_{i,l}}$, $x_{v_{i,h}}$, $y_{v_{i,l}}$, $z_{v_{i,l}}$, and $z_{v_{i,h}}$ are binary variables, they must meet the following constraints.

$$\begin{aligned} x_{v_{i,l}} &\in \left\{0,1\right\} \\ y_{v_{i,l}} &\in \left\{0,1\right\} \\ z_{v_{i,l}} &\in \left\{0,1\right\} \\ z_{v_{i,h}} &\in \left\{0,1\right\} \\ x_{v_{i,l}} + y_{v_{i,l}} + z_{v_{i,l}} + z_{v_{i,h}} &= 1 \end{aligned} \tag{5}$$

In the transcoding hit mode, there are two options to meet the user's request. Considering the constraints of the cache capacity and computing power of the MEC server, we consider content placement and transcoding scheduling to improve the overall performance of the system. If the system transcodes $r_{v_{i,h}}$ as $r_{v_{i,l}}$, the difference between $v_{i,h}$ and $v_{i,l}$ is represented as $s_{v_{i,h}} - s_{v_{i,l}} = (r_{v_{i,h}} - r_{v_{i,l}}) * t$. The transcoding cost is determined by three factors: the input bit rate, the target bit rate and the video length. The transcoding cost is proportional with the size of the processed data. It needs to balance the transcoding cost and loopback cost.

On the other hand, it can be seen that the user's QoE experience is strongly related to the bit rate version and pause time of the video. The pause time is determined by the response time of the video request which includes the transmission delay and the processing delay in the MEC server. Since we consider the trade-off between various strategies, the processing delay mainly considers the impact of transcoding delay. Directly caching the vides to increase hit rate can obtain fast response time. We prefer to cache more high bit rate video content in the MEC server. However, due to the limited storage size of the edge server and the large video segment of the high bit rate version than that of the low bit rate version, it will occupy a larger cache to result in the reduction of the number of cached videos and increase the overall transcoding delay and transmission delay. In fact, affected by the different network environment of users, the video segments of low bit rate version are more likely to be requested by more users. We should weigh and compromise the caching and transcoding of video segments with high bit rate and high popularity based on the popularity of different bit rates.

In order to effectively enhance the overall performance of the system and the overall QoE of users, we need to comprehensively consider the system cost and QoE, and schedule video requests through caching strategy and transcoding strategy. We design the joint optimization problem of cache and transcoding of MEC sever through user request model, delay model, QoE model and cost model.

The probability distribution vector of the video segment set is represented as $\{p_1, \ldots, p_n\}$ ($\sum_{i=1}^{n} p_i = 1$). The p_i represents the probability of that video v_i is requested. If the probability follows Zipf distribution, the probability can be obtained by the following equation.

$$p_i = \frac{k}{i^\alpha}, \quad k = \frac{1}{\sum_{i=1}^{n} \frac{1}{i^\alpha}}, \quad v_i \in V \tag{6}$$

In equation (6), α represents skewness level in the popularity curve ($\alpha > 0$). The same video with different bit rate follows normal distribution. Then, the probability of l^{th} version of video is rewritten as follows:

$$p_i = \frac{e^{-\frac{(l-m)^2}{2\sigma^2}}}{\sqrt{2\pi}\sigma} \tag{7}$$

In Equation (7), m and σ^2 are mean and variance, respectively. The probability of that video v_i with l^{th} bit rate is written as follows:

$$p_{v_{i,l}} = p_{v_i} * p_l \tag{8}$$

The quality of experience (QoE) plays an important role in the Internet video applications. The QoE is effected by the experience quality perceived by the adaptive video streaming client, startup delay, average playback bit rate, and bit rate switching. The video quality depends on the video bit rate. The video bit rate is directly related to the perceived quality of video. Higher compression produces a smaller bit rate but lower perceptual quality. It still needs to balance video bit rate and pause rate. The high bit rate streams increase the possibility of experiencing pause events, since there is a higher chance that the download throughput will be reduced below this bit rate due to contention on the bottleneck link or reduced wireless link quality. Low quality streaming reduces the possibility of pause, but also significantly reduces the quality of the customer experience.

The startup delay is the duration of time that the client needs to reach the target buffer fill level. It is associated with the waiting time from the click of the client to the start of playback. The impact of startup delay on audience dissatisfaction is significantly less than that of stall event.

Stall ratio refers to the total duration time of the session to stop video playback. Low download throughput will lead to a pause event when the playback buffer is empty. It is important to avoid stall events because they play an important role to effect QoE. When the total amount of resources is enough to support the minimum available video bit rate of all clients, it needs to avoid pause events as much as possible.

Frequent quality transcoding is harmful to QoE. It seems that q_{v_l} represents the QoE to associate with video v_l. The QoE of whole system q_{sys} can be represented by the weighted sum of the corresponding measures of all video blocks QoE..

$$q_{sys} = vl \sum_{i=1}^{n} \sum_{j=1}^{l} p_{v_{i,j}} q_{v_{i,j}} \tag{9}$$

The video quality q_{v_l} is determined by the bit rate r_{v_l}. However, the bit rate does not directly reflect the video quality. It needs to map the bit rate to the video quality through the following equation.

$$q_{v_l} = \ln\left(r_{v_l} + 2\right) \tag{10}$$

The delay constraint is one of the main challenges that video service providers should face. The audience suffers network delay, transcoding delay and broadcast delay. In this paper, we focus on the delay caused by the return link from the source server or adjacent MEC server node to the destination MEC server node. The associated cost includes caching, transcoding, and transmission. Let w_c represent the caching cost at MEC server node per video. The caching cost for video v_i is represented as follows:

$$c_v = w_c * t * r_v \tag{11}$$

The transcoding cost is represented as follows:

$$c_s = w_c * D_s = w_s * cm * t * \frac{r_{v_h} - r_{v_l}}{f_0} \tag{12}$$

In Equation (12), D_s represents transcoding delay. Let w_{t0} and w_{t1} represent the transmission cost of transmission link from MEC server provider to source server and the link from MEC server provider to adjacent MEC server node. The associated cost is rewritten as follows:

$$c_{t0} = w_{t0} * t * r_v \tag{13}$$

$$c_{t1} = w_{t1} * t * r_v \tag{14}$$

The total cost is represented as following equation.

$$c_{total} = c_v + c_s + c_{t0} + c_{t1} \tag{15}$$

In order to implement cache transcoding resource scheduling with low cost and high QoE, we define the optimization problem as follows:

$$\begin{aligned} \min_{x_{v_l}, y_{v_l}, z_{v_l}, z_{v_h}} \ : \ & \alpha * c_{total} - \beta * q_{total} \\ & \sum_{i=1}^{n} \sum_{j=1}^{l} x_{v_{i,j}} * t * r_{v_{i,j}} \le M \\ & \sum_{i=1}^{n} \sum_{j=1}^{l} y_{v_{i,j}} * cm * t * \left(r_{v_{i,h}} - r_{v_{i,l}} \right) \le f_0 \\ & y_{v_{i,j}} \le x_{v_{i,j}} \\ & x_{v_l} \in \{0,1\}, \quad y_{v_l} \in \{0,1\}, \quad z_{v_l} \in \{0,1\}, \quad z_{v_h} \in \{0,1\} \\ & x_{v_l} + y_{v_l} + z_{v_l} + z_{v_h} = 1 \end{aligned} \tag{16}$$

The objective function in optimization problem (16) is to minimize the total cost as well as maximize total QoE. It covers caching, transcoding, and transmission delay and caching, transcoding, and transmission cost.

The combination of caching and transcoding is a integer linear programming which is a NP-hard problem. It can be solve by an evolution algorithm to obtain an approximate solution, such genetic algorithm (Whitley 1994), ant colony algorithm (Dorigo 2006), and simulated annealing algorithm (Rutenbar 1989). In this paper, the ant colony algorithm is adopted to solve Equation (16).

4. EXPERIMENTS AND SIMULATIONS

In this section, we establish a simulation environment to verify the proposed caching and cost optimization strategy for mobile edge computing architecture in online education. For the video cache transcoding process, we focus on the following three strategies. The first strategy considers caching, transcoding and backhaul. When a transcoding hit occurs, the mobile edge computing server can respond to the user by transcoding or requesting video content from the source server or the adjacent mobile edge computing server.

The second strategy only considers backhaul in which the video requests can only be transmitted through the network to the source server for response.

The third strategy considers caching and transmission in which the mobile edge computer server only has caching function and does not have transcoding capability.

The results of total QoE with the number of videos are reported in Figure 2, while the results of total cost with the number of videos are reported in Figure 3.

Figure 2. The curve between the number of videos and the total QoE

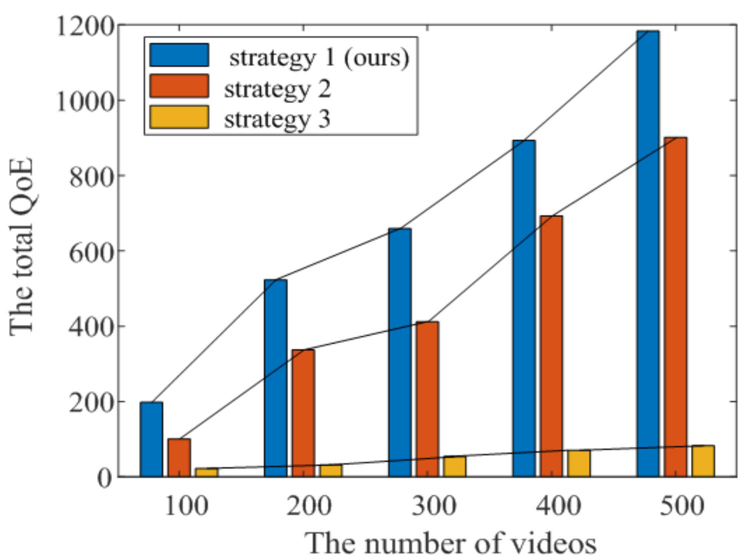
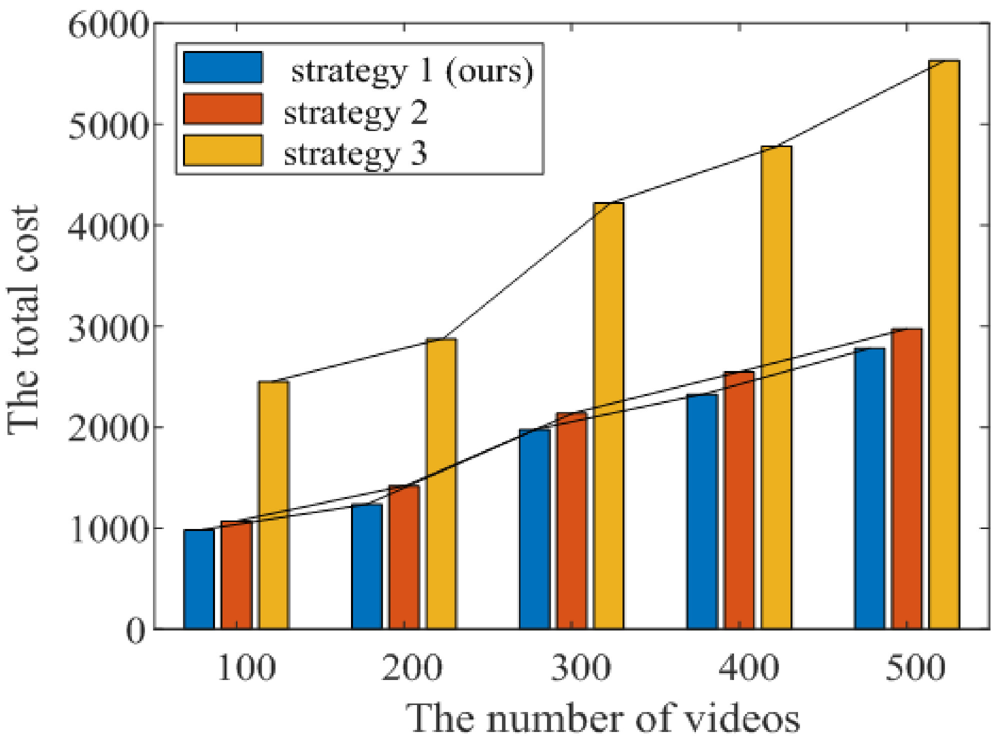


Figure 3. The curve between the number of videos and total cost



From results in Figure 2, it can be found that the total QoE increases with the number of videos in three strategies and the proposed strategy can obtain better total QoE than both strategy 2 and strategy 3. From the results in Figure 3, it can be found that the total costs increases with the number of videos in three strategies and the proposed strategy cost fewer than both strategy 2 and strategy 3.

5. CONCLUSION

In this paper, we establish a mobile edge computing (MEC) based live video distribution system to support online education. Compared with content delivery network (CDN) based live video distribution, the MEC based live video distribution system has better mobility. The cache transcoding resources in MEC based live video distribution is optimized by the joint optimization which comprehensively considers the overall cost consumption on the network side and the overall QoE optimization on the user side. The joint optimization can effectively schedules the cache, transcoding and return strategies of video content to improve the overall performance of the system. The proposed optimization is solved by ant colony algorithm. The experimental results show that the proposed strategy can significantly improve the performance of the live video distribution system.

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