



Minimize the Cost of Video Transmission Among Cloud Data Center and Edge Cloud CDN Nodes

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Abstract. With the development of cloud computing, more and more video service providers use services from cloud providers. A video service provider can construct a scalable video streaming platform with high availability by the cloud services. Typically, a video service provider uploads its video data to a cloud data center. Then, the cloud data center distributes the video data to its edge cloud CDN nodes. Usually, the cloud data center links with its edge cloud CDN nodes by high-capacity links, spanning different geographical regions. Video traffic across the cloud data center and the edge cloud CDN nodes of a cloud provider, brings on large operational cost to the cloud provider. How to reduce the video traffic cost is important for a cloud provider. Therefore, to reduce the video traffic cost, we propose a set of algorithms based on network maximum flow and minimum cut, called *Netcut-way*. The proposed *Netcut-way*, charged by the peak-bandwidth billing model, consists of three parts. The first is peak bandwidth calculation. The second is video segment segmentation. The third is video distribution route. Through extensive simulations, we demonstrate that *Netcut-way* can effectively reduce the operational cost of cloud providers in video traffic across data centers.

Keywords: Cloud data center · Edge cloud CDN nodes · Video traffic cost

1 Introduction

In order to provide end users with rich video resources and reduce management costs, video streaming service providers usually combine with cloud service, such as Tencent cloud service, Alibaba CDN cloud service and Amazon Web Services (AWS). For example, Tencent cloud service uses a simple storage service to store all source video data in one cloud data center. Then, Tencent cloud service converts the video data into a certain format, and distributes the formatted video data to its edge cloud CDN nodes in different regions [1]. The edge cloud CDN nodes can provide video streaming services to their nearby end users' terminals. Thus, the video transmission delay can be reduced, and user experience can be improved.

To enable end users to timely obtain reliable video resources and improve the high availability of the network, data resources in cloud data centers should share video resources to the maximum extent [2]. Cloud service providers usually deploy more edge cloud CDN nodes in different regions [3], which are connected by leased high-capacity links. Previous research reveals that traffic costs amount to around 15% of operational costs incurred to a cloud provider [4]. Video traffic among cloud video center and edge cloud CDN nodes usually constitutes a large portion of a cloud service provider's inter-datacenter traffic. Thus, the video traffic of a cloud service provider, across data centers, brings on large operational cost to the cloud service provider. Therefore, how to effectively reduce the video transmission cost for cloud service providers is important.

Because most cloud service providers rely on multiple ISPs to connect to geographically dispersed edge cloud CDN nodes [5], to effectively reduce the video transmission cost across different regions, the costs charged by Internet Service Providers (ISPs) should be reduced or even be minimized. Suppose percentile-based charging models currently used by most ISPs are applied [6], e.g. the 95-th percentile charging model, the previous research has demonstrated that reducing the cost of inter data-datacenter video traffic is feasible [7]. However, the previous research didn't consider the availability of video data [8]. In this paper, we consider the availability of video data, focusing on the case that video data are delivered from one data center to other edge cloud CDN nodes. Therefore, to reduce the video transmission cost among datacenters, we propose a new set of algorithms based on network maximum flow and minimum cut, called *Netcut-way*. *Netcut-way* consists of three parts. The first is peak bandwidth calculation. The second is video segment segmentation. The third is video distribution route. Then, through extensive simulations, we demonstrate that *Netcut-way* can effectively reduce the video transmission cost.

The remainder of this paper is organized as follows. In Sect. 2, we discuss the related work. In Sect. 3, we present the rationale and cloud network model of our work. In Sect. 4, we propose a new set of algorithms based on network maximum flow and minimum cut, called *Netcut-way*. In Sect. 5, the performance of *Netcut-way* is demonstrated. Finally, we conclude the paper in Sect. 6.

2 Related Work

At present, with the development of big data and cloud computing, many cloud service providers distribute multiple edge cloud CDN nodes in different geographical regions, which enables the cloud system to provide a wider range of services with low latency. But some problems have been brought to people's attention. Lei Jiao studied the dynamic OSN on multiple geographically distributed clouds in a continuous cycle [9], and at the same time met the predefined QoS and data availability requirements, thus obtaining the most advanced method to significantly reduce one-time costs on the premise of ensuring QoS and data availability. Yu Wu et al. proposed to carry out effective storage and migration between different cloud sites at an appropriate cost, and adopted the optimal content migration and request distribution based on efficient optimization algorithm to solve the prediction demand [10]. Sem C. Borst proposes to

alleviate these huge bandwidth requirements and performance bottlenecks by copying the most popular content closer to the edge of the network, rather than storing it at a central site [11]. Leana Golubchik et al. proposed that under the 95% charging model [12], the first 5% (95% time) of data transmission would not affect the transmission cost. In such an environment, we can greatly reduce costs by allowing some brief delays in data transmission. A. Mahimkar proposed that cloud providers use replication of geographically distributed data centers to improve end-to-end performance and high availability in the case of failure. However, previous studies did not consider the availability of video data. In this paper, the difference of our work is that we consider the availability of video data, and focus on how to transmit video data from one data center to other edge cloud CDN nodes at low cost.

2.1 System Overview

This system adopts the content distribution network model deployed by hierarchical nodes [13]. Figure 1 shows the cloud network model. The innermost layer is cloud video data center, the next layer is edge cloud CDN node, and the outermost layer is user terminal. The cloud data center deploys a stream source server, a central index server, some secondary servers, and so on. Streaming media source servers store many video resources uploaded by video service providers. The central index server maintains the video information of each edge cloud CDN node and responds to client requests [14]. First, the cloud data center distributes video clips to the edge cloud CDN node, making the edge cloud CDN nodes cache part of the video data [15]. Then, when another edge cloud CDN node requests a video clip at a minimum cost on the path, the response node obtains a copy based on the resource replication policy and forwards the copy to the requesting node [16]. In this network system, edge cloud CDN node can request the lost video clip from other nodes and record the updated video clip information of the neighbor node [17].

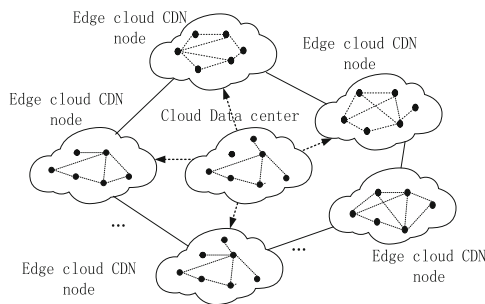


Fig. 1. the cloud network model

2.2 Overlay Structure Construction

Aiming at the video transmission strategy in the cloud, this paper studies how to reduce the cost of video transmission between cloud data center and edge cloud CDN nodes [19]. First, the video service provider uploads the video resources to the cloud data center. When the streaming media source server located in the cloud data center transmits video to the edge cloud CDN node, the cloud service provider rents multiple ISP lines. In this way, ISP service providers will charge cloud service providers based on video traffic. ISP provides peak bandwidth pricing strategy. In this strategy, ISP regularly collect peak bandwidth on leased lines and charge for maximum peak bandwidth. In this way, the paid-for link bandwidth can be utilized as much as possible without adding additional cost, thus reducing the cost of video transmission. This is also the basis for reducing the cost of video transmission between cloud data center and edge cloud CDN node. On this basis, we mainly divided into two stages. In the first phase, the cloud data center sends different video clips to the edge cloud CDN node according to the link's historical peak bandwidth. In the second stage, the minimum cost path between nodes is calculated based on the historical bandwidth peak of the current link. When a certain video fragment is missing from an edge cloud CDN node, it is necessary to select the path with the lowest cost to request the required video fragment from other nodes.

3 Minimum Cost Method for Video Distribution

3.1 Cloud Network Model Analysis

Before the minimum path algorithm for cloud video transmission cost is proposed, we first introduce the cloud network model in this paper regarding the traffic between cloud data center and edge cloud CDN node. The important symbols used in this article are listed in Table 1.

We consider the deployment of cloud data center and edge cloud CDN nodes. Cloud data center and edge cloud CDN nodes are connected through multiple highly available links. We use directed graph $G(V, E)$ to represent the network deployment model. For each link $\{i, j\} \in E$, cost per unit bandwidth of link $\{i, j\}$ is a_{ij} . We use C_{ij} to represent Maximum available bandwidth capacity of link $\{i, j\}$ and r_k to represent the expected video transmission rate. In the case of network congestion, the video transmission rate is lower than the expected transmission rate. (Dk, Sk) represents the set of links from the source node to the target node. According to the historical peak bandwidth of the link, the video to be transmitted is divided into segments of appropriate size, and video segments are transmitted between nodes at the lowest cost. f_{ij}^k represents the bandwidth allocated by video K over the link. $C(x) = C * x$ represents the cost of video transmission on the link. If f_{ij}^k is less than the maximum peak value of transmission, the cost is free.

Table 1. Notations and definitions

Notation	Definition
V	The number of nodes in the network
E	A set of all directed links connecting edge cloud CDN nodes
K	The size of the data stream of the video
(S_k, D_k)	A collection of links for source and destination nodes
rk	Represent the expected video transmission rate
C_{ij}	Maximum available bandwidth capacity of link $\{i, j\}$
a_{ij}	Cost per unit of bandwidth on link $\{i, j\}$
f_{ij}^K	Video stream K allocates bandwidth on link $\{i, j\}$
$maxf_{ij}^K$	Maximum bandwidth peak on link $\{i, j\}$
$d_{ij}(t)$	The bandwidth of other nodes in the network during time t
$cost_{ij}(t)$	The cost of link $\{i, j\}$ over a period

If we use f_{ij} to denote the maximum video transmission bandwidth that a link can allocate, then the total bandwidth of link $\{i, j\}$ can be expressed as follows:

$$f_{ij} = \sum f_{ij}^K(t) + d_{ij}(t) \quad (1)$$

In the above formula, $d_{ij}(t)$ represents the bandwidth of other nodes in the link at a certain time, f_{ij}^K represents video stream K allocates bandwidth on link $\{i, j\}$.

3.2 Algorithm Analysis

Cloud video transmission cost consists of three modules. The first module is the cloud link status monitoring module, which can obtain the historical bandwidth traffic and current link congestion. The second module is the video segmentation module. According to the peak bandwidth, the response node can divide the video into appropriate segment sizes and forward it to the requesting node with the lowest cost path. The third module is the design of the least-cost path algorithm, which calculates the least-cost path between edge CDN nodes in the cloud based on the historical peak bandwidth of each link and the node video stream cache. We use $cost_{ij}(t)$ to represent the cost of the link $\{i, j\}$ transmitted in the network, then the following formula can be obtained:

$$cost_{ij}(t) = a_{ij}maxf_{ij}^K \quad (2)$$

According to Eq. (5), the current link bandwidth cost can be rewritten as follows:

$$cost_{ij}(t) = \begin{cases} cost_{ij}(t-1) & f_{ij}(t) \leq max_{t-1}f_{ij} \\ a_{ij}maxf_{ij}^K & otherwise \end{cases} \quad (3)$$

If $K_f(t)$ represents the historical bandwidth peak in the time interval of t-1, then the link {i, j} link bandwidth peak at time t is:

$$f_{ij}^K(t) \leq \min(\max_{t-1} f_{ij}, c_{ij}(t) - d_{ij}(t)), \forall \{i, j\} \tag{4}$$

$$\sum_{j \in V} f_{Skj}^K(t) = \sum_{j \in V} f_{jDk}^K$$

$$f_{ij}^K \geq 0, \forall k \in K_{f(t)}, \forall \{i, j\} \in E$$

Based on the above analysis, in order to reduce the cost of cloud video transmission between edge CDN nodes in cloud, we design a set of *Netcut-way* algorithms. The algorithms are divided into three parts. One is the calculation of peak bandwidth. The second is video segmentation. Third, the minimum cost path.

According to Algorithm 1, peak bandwidth is calculated as follows [20]. First, the system sets the initial capacity value and the initial bandwidth peak. The edge cloud CDN node counts and monitors the link status between the cloud data center and each edge cloud CDN node every 5 min to get the current bandwidth peak of the link. The maximum peak value of the link is updated based on the bandwidth obtained.

Algorithm 1 Determine the maximum link history bandwidth peak algorithm

- 1 Obtain the initial solution f^1, f^2, \dots, f^i
 - 2 Set the maximum peak bandwidth is f^K
 - 3 **while** $f^i \in (f^1, f^2, \dots, f^{i-1})$ **do**
 - 4 **for Each** $k \in K_{f(t)}$ **do**
 - 5 Find the max flow $(f^1, f^2, \dots, f^{i-1}) = f^K$
 - 6 **if** $(f^i > f^K)$ **then**
 - 7 update $f^K = f^i$
 - 8 **End if**
 - 9 **End for**
 - 10 **End While**
 - 11 **Return** f^k
-

If we use $(f_1^K, f_2^K, f_3^K, \dots, f_i^K) \in K(t)$ means that the node divides the video into segments of appropriate size, and distributes the video to other nodes through the

minimum path algorithm. When the node can transmit the video clip with the maximum bandwidth, the following formula can be obtained:

$$\forall \{i, j\} \in E, \sum_k f_i^K \leq c_{ij} \tag{5}$$

In view of the above analysis, we design Algorithm 2 to solve the problem of node video segmentation. The node can transmit as many free video clips as possible without exceeding the maximum historical peak of the link.

Algorithm 2 Bandwidth allocation based on historical peak bandwidth

- 1 The node divides the video into segments of appropriate size clips $(f_1^K, f_2^K, f_3^K, \dots, f_i^K)$
 - 2 The max capacity bandwidth of the link $C_{ij}(\{i, j\} \in E)$
 - 3 **While** $(f_1^K, f_2^K, f_3^K, \dots, f_i^K)$ **do**
 - 4 **Algorithm 1** obtains the historical bandwidth peak of the link f^K
 if $(f_i^K(t) < f^K)$ **do**
 - 5 The free video transmission clip is $f_i^K(t)$
 else
 - 6 Update $f_i^K(t) = C_{ij} - d_{ij}(t)$
 - 7 **End While**
 - 8 **Return** $(f_1^K, f_2^K, f_3^K, \dots, f_i^K)$
-

The design of the minimum cost path algorithm is the focus of this paper. Based on maximum flow and minimum cut, we design Algorithm 3 [21]. First, we use Algorithm 2 to solve the video segmentation problem. Cloud data center divides video K into segments $(f_1^K, f_2^K, f_3^K, \dots, f_i^K)$. The edge cloud CDN node saves the video clips distributed by the cloud Data center. Then the edge cloud nodes run the algorithm to find the least cost path to request the lost video clips from other nodes.

Algorithm 3 Maximum network minimum cut minimum cost algorithm

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1   Set the video resource of cloud center node to  $K$ 

2   Algorithm 2 divides video streaming  $K$  into segments of appropriate
    size( $f_1^K, f_2^K, f_3^K, \dots, f_i^K$ )

3   Cloud data center takes video clips ( $f_1^K, f_2^K, f_3^K, \dots, f_i^K$ ) on different edge
    Cloud CDN nodes through different links

4   Edge cloud node saves video clips ( $f_1^K, f_2^K, f_3^K, \dots, f_i^K$ )

5   Suppose an edge cloud CDN node requests a video clip  $f_i^K$ 

6   Set a queue  $Q$  to represent the currently unchecked label point

7   path: Marks the nodes that the current path passes through

8   Repeat:

9       path==null

10  The source point  $Sk$  is marked and enters queue  $Q$ 

11  While ( $Q \neq \text{null}$  and  $Dk$  is not remarked) do

12      Begin:

13           $u=Q.$  remove ()

14          for (edge ( $u, v$ ) that starts from  $u$ ) do

15              if ( $v$  is the node marked and ( $u, v$ ) which can) do

16                   $Q.$  add( $v$ ), path. add( $v$ )

17              End if

18          End for

19  End while

20      if ( $Dk$  is marked) do

21          Modify traffic along the path from  $Dk$ 

22  until ( $Dk$  marked)

23  Return ( $f_1^K, f_2^K, f_3^K, \dots, f_i^K$ )
  
```

4 Performance Evaluation

In this section, we demonstrate the performance of the *Netcut-way* algorithms through simulation. Firstly, the simulation steps and evaluation indexes are introduced. The performance of the algorithms is represented by the figures. Then compared with *Jetway* algorithms, the performance of our algorithms is superior to *Jetway* algorithms

4.1 Simulation Setup

We implemented an event-driven simulator on the PeerSim simulation platform to evaluate the performance of *Netcut-way*. We built a cloud video transmission system and stored all the video clips in the cloud data center. First, different initial transmission delays and initial bandwidth peaks are randomly set in the system link. In the experiment, considering the difficulty of the experiment, we set up 40 edge cloud CDN nodes. At the same time, we also set the video source size to 20 TB, and the expected transmission rate range of video is [3.31,15.72] Mbps. First, the cloud data center splits the appropriate video clips and distributes them to other edge cloud CDN nodes. Edge cloud CDN nodes cache some video clips received. As can be seen from Fig. 2, the edge cloud CDN node contains edge streaming media server and edge index server. The edge index server is responsible for discovering neighbor nodes and finding the minimum cost path to the destination node. The edge streaming server is responsible for storing video stream. Moreover, when other edge cloud CDN nodes request the missing video clips, the edge stream server can respond to the request and generate video clips copies to distribute to the requesting nodes with the least cost path.

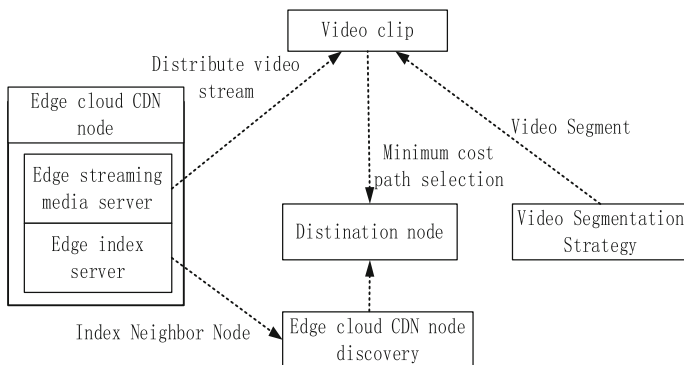


Fig. 2. logic structure of the simulation

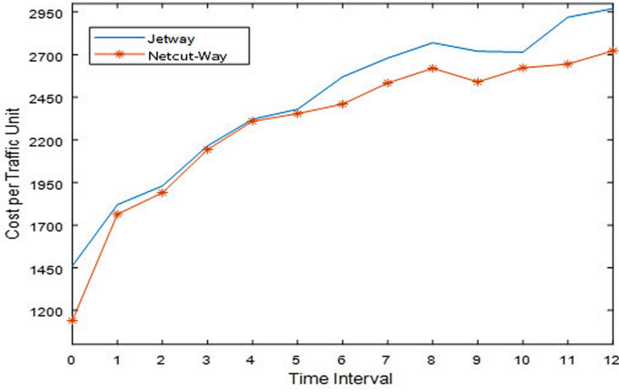


Fig. 3. Based on 100% charge mode per unit cost

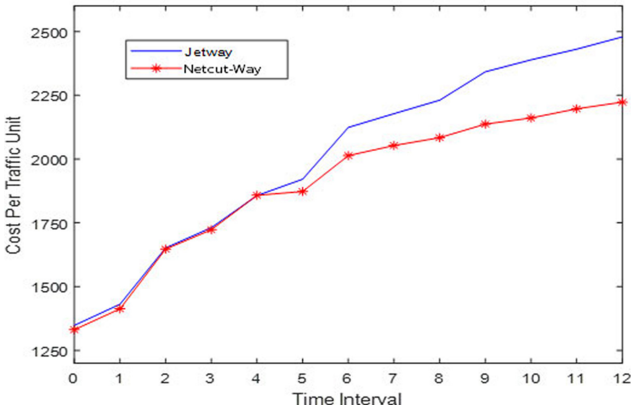


Fig. 4. Based on 95% charge mode per unit cost

4.2 Simulation Result

(1) Unit transportation cost

Unit transport cost is defined as the unit video transmission cost of a system over a period. In the experiment, we recorded the video transmission cost of edge cloud CDN node in different time periods. We consider the maximum capacity of network bandwidth in the case of video segment transmission units on each link, regardless of the importance of the time dimension. Figure 3 and Fig. 4 show the unit transmission costs of *Jetway* and *Netcut-way* in different charging model, respectively. As can be seen from the figure, the unit transmission cost of *Netcut-way* algorithms is lower than that of *Jetway* algorithms

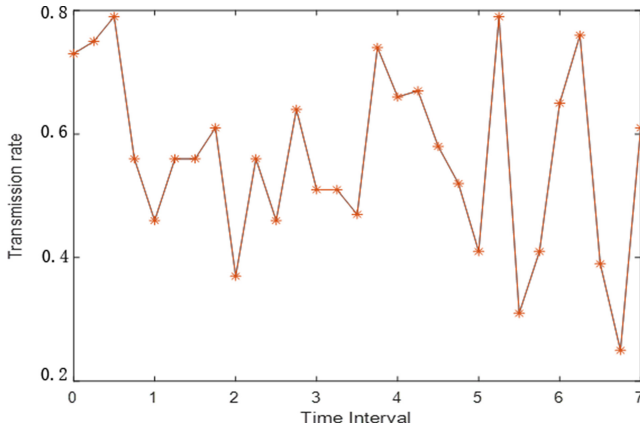


Fig. 5. Video transmission rate of *Netcut-way*

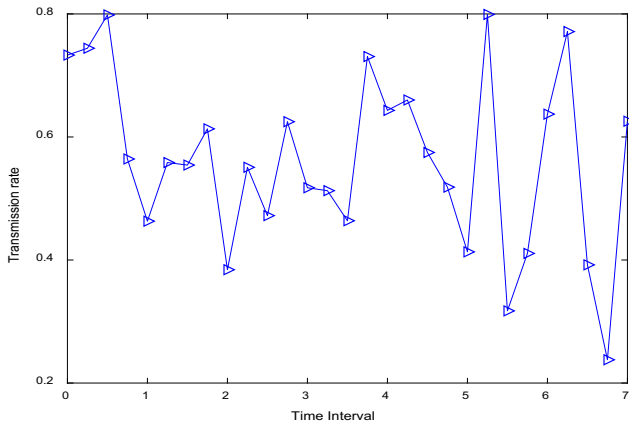


Fig. 6. Video transmission rate of *Jetway*

(2) Video transmission rate

The video transmission rate represents the video transmission rate of edge cloud CDN nodes. In the experiment, we count the transmission rate of the node every 30 s. Figure 5 and Fig. 6 show the node transmission rate in a certain period under the two algorithms. As can be seen from the figure, the video transmission rate of edge cloud CDN node under *Netcut-way* algorithms is basically consistent with that under *Jetway* algorithms. Therefore, our algorithms have little effect on the node transmission rate.

(3) Actual and expected transfer rate ratio

The ratio of the actual transmission rate to the expected transmission rate indicates the smoothness of the video transmission. The cloud data center divides the video into appropriate segments and distributes them to the surrounding edge cloud CDN nodes, so that the edge cloud CDN nodes cache a part of the video clips received from the cloud data center. With the increase of the number of requests and cache video clips, many video clips can be transmitted through the least cost path, which makes edge cloud CDN nodes cache more and more videos. Figure 7 shows the results of *Netcut-way* and Fig. 8 shows the results of *Jetway*. As can be seen from the figure, the transmission efficiency of *Netcut-way* algorithms is higher than that of *Jetway* algorithms.

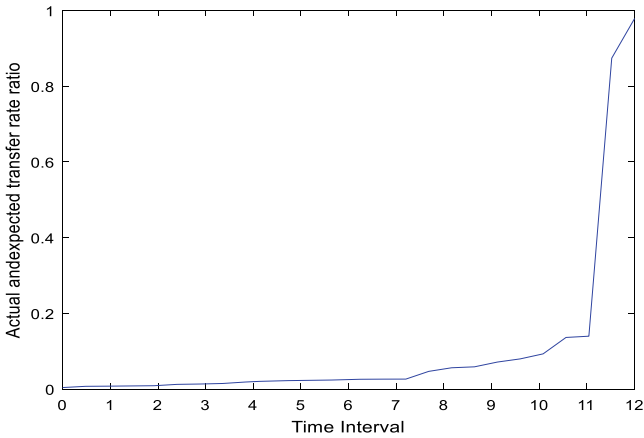


Fig. 7. Actual and expected transfer rate ratio of *Netcut-way*

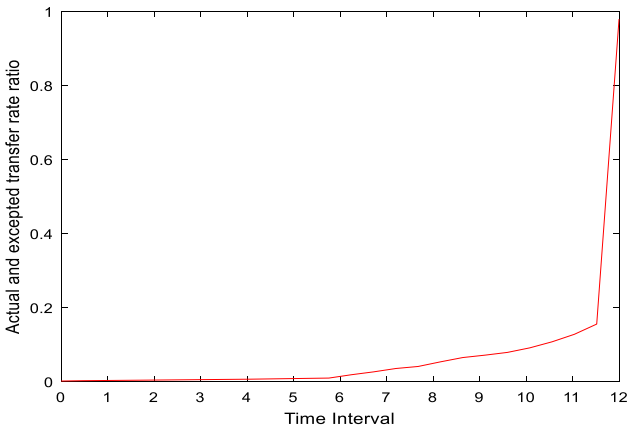
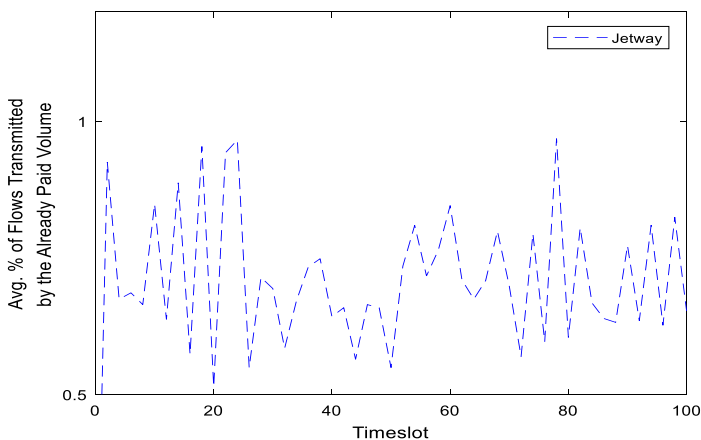


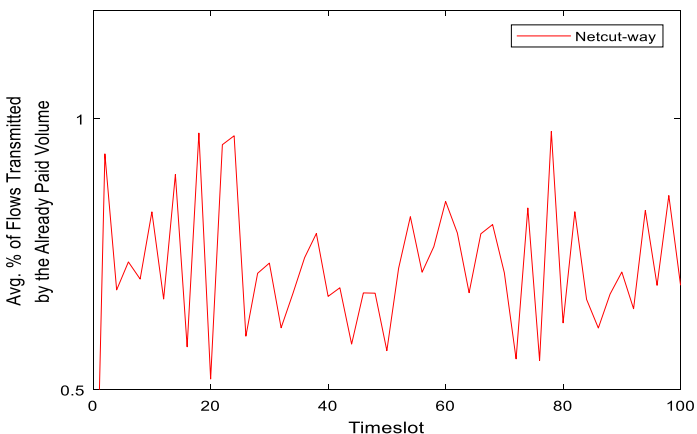
Fig. 8. Actual and expected transfer rate ratio of *Jetway*

(4) Cost reduction percentage

In order to further analyze the cost reduction under *Netcut-way* algorithms and *Jetway* algorithms, we draw the video transmission cost diagram of the two algorithms in a certain period. Figure 9.a shows the implementation of *Jetway* algorithms, and about 75% of the video clips are realized by means of payment. Figure 9.b is implemented under the *Netcut-way* algorithms, and about 71.7% of the video clips are realized through the payment bandwidth. Therefore, it is showed that *Netcut-way* algorithms can further reduce the operating cost of cloud service providers than *Jetway* algorithms.



(a) cost reduction percentage of *Jetway* algorithms



(b) cost reduction percentage of *Netcut-way* algorithms

Fig. 9. Cost reduction percentage

5 Conclusions

Currently, ISP service providers have a variety of pricing methods, such as traffic-based billing, peak bandwidth billing. Cloud service providers typically deploy multiple edge cloud CDN nodes in different geographic locations and rent a highly available ISP link to transmit video data. In order to reduce the cost of video transmission for cloud service providers, this paper proposes the *Netcut-way* algorithms based on peak bandwidth billing model. The algorithms can effectively reduce cloud video transmission cost and cloud video transmission delay between edge cloud CDN nodes. Finally, through the comparison of experimental results of *Jetway* algorithms, it can be demonstrated that *Netcut-way* algorithms can effectively reduce the operating cost of cloud service providers and is more effective than *Jetway* algorithms.

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References

1. Zhao, Z., Sheng, Y., Wang, J., Zhu, M.: An in-network service system based on smart routers and edge devices. In: 2017 20th International Symposium on Wireless Personal Multimedia Communications (WPMC), Bali, pp. 568–574 (2017). <https://doi.org/10.1109/wpmc.2017.830187>
2. Chen, Y., et al.: Packet cloud: a cloudlet-based open platform for in-network services. *IEEE Trans. Parallel Distrib. Syst.* **27**(4), 1146–1159 (2016). Article (CrossRef Link)
3. Mahimkar, A., et al.: Bandwidth on demand for inter-data center communication. In: Proceedings 10th ACM Workshop on Hot Topics in Networks (HotNets), pp. 1–6 (2011). Article (CrossRef Link)
4. Tencent. <https://www.it610.com/article/2066413.html>. Article (CrossRef Link)
5. Greenberg, A., Hamilton, J., Maltz, D.A., Patel, P.: The cost of a cloud: research problems in data center networks. *SIGCOMM Comput. Commun. Rev.* **39**(1), 68–73 (2009)
6. Zhang, Z., Zhang, M., Greenberg, A., Hu, Y.C., Mahajan, R., Christian, B.: Optimizing cost and performance in online service provider networks. In: Proceedings 7th Conference on Networked Systems Design and Implementation (NSDI), pp. 1–15 (2010)
7. RouteScience Technologies, Route Optimization for Ebusiness Applications. White Paper (2003)
8. Jetway: Minimizing Costs on Inter-Datacenter Video Traffic
9. Jiao, L., Li, J., Xu, T., Du, W., Fu, X.: Optimizing cost for online social networks on geo-distributed clouds. *IEEE/ACM Trans. Networking* **24**(1), 99–112 (2016). <https://doi.org/10.1109/tnet.2014.2359365>. Article (CrossRef Link)
10. Zhu, J., et al.: Scaling Service-Oriented Applications into Geo-distributed Clouds (2013). Article (CrossRef Link)
11. Borst, S., Gupta, V., Walid, A.: Distributed caching algorithms for content distribution networks. In: Proceedings-IEEE INFOCOM, pp. 1478–1486 (2010). <https://doi.org/10.1109/INFCOM.2010.5461964>. Article (CrossRef Link)

12. Golubchik, L., Khuller, S., Mukherjee, K., Yao, Y.: To send or not to send: Reducing the cost of data transmission. In: 2013 Proceedings IEEE INFOCOM, Turin, pp. 2472–2478 (2013). <https://doi.org/10.1109/infcom.2013.6567053>. Article (CrossRef Link)
13. Sajithababu, S., Balasundaram, S.R.: Direct push-pull, or assisted push-pull? Toward optimal video content delivery using shared storage-based cloud CDN (SS-CCDN). *J. Supercomputing* **75**(4), 2193–2220 (2019). Article (CrossRef Link)
14. Hu, H., et al.: Joint content replication and request routing for social video distribution over cloud cdn: a community clustering method. *IEEE Trans. Circuits Syst. Video Technol.* **26**(7), 1320–1333 (2016). Article (CrossRef Link)
15. Al-Habashna, A., et al.: Distributed cached and segmented video download for video transmission in cellular networks. In: International Symposium on Performance Evaluation of Computer and Telecommunication Systems. IEEE (2016). Article (CrossRef Link)
16. Liu, P., Feng, S., Huang, G.: Bandwidth-availability-based replication strategy for P2P VoD systems. *The Comput. J.* **57**(8), 1211–1229, August 2013. Article (CrossRef Link)
17. Zhang, Z., Zhang, M., Greenberg, A., Hu, Y.C., Mahajan, R., Christian, B.: Optimizing cost and performance in online service provider networks. In: Proceedings 7th Conference on Networked Systems Design and Implementation (NSDI), pp. 1–15 (2010). Article (CrossRef Link)
18. Laoutaris, N., Sirivianos, M., Yang, X., Rodriguez, P.: Inter-datacenter bulk transfers with NetStitcher. In: Proceedings ACM SIGCOMM (2011). Article (CrossRef Link)
19. Peng, G.: CDN: content distribution network. Research Proficiency Exam Report (2003). Article (CrossRef Link)
20. Ai-Ping, Z., Guang, C.: Analysis of network behavior characteristic and influence factor based on the peak traffic. *J. Commun.* **33**(10), 117–125 (2012). Article (CrossRef Link)
21. Wang, M., Li, B.: Linear network coding. *IEEE Trans. Inf. Theory* **49**(2), February 2003. Article (CrossRef Link)