Classification-based Multi-client Video Transmission over Heterogeneous Networks

Bo Li, Peng Wang, and Yongfei Zhang
Beijing Key Laboratory of Digital Media, School of Computer Science and Engineering, Beihang University, Beijing 100191, China
Email: bhboli@vip.sina.com, knightwp@126.com, zhangyf.ac@gmail.com

***Abstract*—These Real-time video streaming over networks operates under stringent network resource constraints, with multiple video clients competing for limited network resources. In this paper, we study the problem of bandwidth allocation for video transmission over heterogeneous networks, with multiple video clients connecting to the video server simultaneously and demanding for the video services, and aim to provide the best possible Quality of Service (QoS) under limited bandwidth of both the video server and multiple video clients. We propose a classification-based approach for multi-client video transmission over heterogeneous networks (CMVT). Firstly, the video server detects the available bandwidth of multiple video clients and classifies the clients into different classes. Secondly, the limited export bandwidth of the server is allocated to different video clients using the client classification results and greedy algorithm. Finally, the video server transmits video streams to video clients in different classes through Unicast and clients in the same class through Unicast and forwarding. Experimental results demonstrate that the proposed video transmission method can use the network bandwidth efficiently and provide better video quality to more video clients.**

***Index Terms*—Video Transmission, Client Classification, Bandwidth Allocation, Unicast and Forwarding**

I. INTRODUCTION

With the fast development of the real-time video demands and networking techniques, real-time video applications are playing more and more important role in the industrial area as well as our daily lives, a lot of video transmission schemes have also been proposed in the literature.

Generally, in real-time video transmission, a single video stream cannot satisfy the requirements of multiple video clients in a heterogeneous network environment [1], because the available bandwidth of each video client might be different. What is more, when multiple video clients connect to the video server simultaneously, they have to compete for the limited export bandwidth of the video server. If the limited export bandwidth cannot be allocated to video clients reasonably, the reconstructed video quality provided to the video clients would severely degrade.

The most commonly used traditional transmission methods are Unicast, Multicast and Broadcast. Unicast is a commonly used transmission scheme which establishes one connection between each sender and receiver. The control of Unicast is flexible, but it cannot efficiently utilize the network bandwidth. Multicast is used to transmit data from a single sender to multiple receivers simultaneously which can efficiently utilize the network bandwidth. However, the flexibility and security of Multicast is poor [2], [3]. The receivers may attempt to request different video quality with different bandwidth, but only one video stream is sent out from the video server when using Multicast, which cannot meet various requirements of the receivers. Broadcast transmits data from one sender to all the receivers, regardless of whether the receivers need or not. Several Broadcast schemes [4] such as fast broadcast, harmonic broadcast and staggered broadcast have been proposed, and it has been proved that the harmonic broadcast is more efficient than the other broadcast schemes [5]. In [6], [7], video transmission methods combining Broadcast and Unicast are proposed. These methods may consume minimal export bandwidth of the video server, but they may also introduce the broadcast storms easily, which will results in severe network congestions and significant performance degradation. What is more, similar to Multicast, the safety and flexibility issues prevent Broadcast from many practical video applications. Considering the transmission safety and data privacy, most network intermediate devices such as routers/switches in current networks like Internet do not support Multicast and Broadcast and only support Unicast.

In most practical applications, the export bandwidth of the video server is limited, and the resulting transmission bottleneck on the video server side cannot be avoided [8]. So how to allocate the limited export bandwidth and provide better video quality to satisfy the requirements of different video clients becomes a critical issue. Several bandwidth allocation algorithms have been proposed in [9], [10]. These algorithms are either operated on the network intermediate devices or not aiming at the characteristics of the video transmission. But in most practical applications it is not allowed to access the intermediate network devices. More practical solutions are those end-system based schemes which do not require the participation of the networks and are applicable to both the current and future Internet. In [11]-[15], several

This work was partially supported by the 973 Program (No. 2010CB327900), the National Natural Science Foundation of China (No.61272502) and the National Science Fund for Distinguished Young Scholars (No.61125206).

doi:10.4304/jmm.8.4.315-322

rate-distortion optimization-based video transmission algorithms have been proposed. They improve the reconstructed video quality considering the rate-distortion characteristics of the video. But these algorithms are proposed only for single video transmission. When multiple video streams are transmitted in the same network link, the quality of all the video streams should be considered jointly. Moreover, some of these algorithms may bring long capture-to-display latency (CDL) [16] which can not satisfy the real-time requirements in the video applications, especially for the video applications with interactions between the video clients and the video server. In [17], an efficient bandwidth resource allocation algorithm, M-LDLF (Multiuser Low-delay resource allocation algorithm with Low-fluctuation), is proposed. M-LDLF provides low fluctuation of quality for each user and consistent quality among all users by exploring the variation in the scene complexity of each video program and jointly redistributing available system resources among users. Given the limited export bandwidth of video server, M-LDLF may achieve good performance with small number of clients connect to the video server simultaneously. But if there are more clients, the transmission scheme adopted in M-LDLF that one encoder corresponds to one user would cause severe degradation in the reconstructed video quality.

In real-time video applications, when multiple clients with different available bandwidth connect to the video server simultaneously, only one video stream cannot satisfy all the requirements of these clients. On the other hand, it is too expensive or even impossible to generate and transmit a video stream with specific bitrate to accommodate each client using Unicast with guaranteed video quality, since the computational and storage resource as well as the export bandwidth of the video server are limited.

In this paper, we alleviate this dilemma with a novel client-classification-based approach. Aiming to enable more video clients to access the video server simultaneously and obtain better reconstructed video quality under limited export bandwidth of the video server, we propose a classification-based multi-client video transmission (CMVT) scheme over Heterogeneous networks. Firstly, we classify video clients into different classes according to their available bandwidth. Secondly, the greedy algorithm is adopted to allocate the export bandwidth of the video server to different classes using client classification results. Finally, a hybrid video transmission scheme is developed, in which Unicast is used to transmit video streams to the clients in different classes, Unicast and forwarding are both used to transmit video streams to the clients in the same class. The rest of the paper is organized as follows. Section II describes the discriminant analysis-based client classification scheme. In Section III, we present the proposed greedy and client classification-based bandwidth allocation algorithm. The hybrid video transmission scheme is developed in Section IV, followed by the proposed classification-based multi-client video transmission scheme. Section V presents the experimental results and performance comparisons. Finally, the paper is concluded in section VI.

II. DISCRIMINANT ANALYSIS-BASED CLIENT CLASSIFICATION

In this section, we present the discriminant analysis-based client classification scheme. When a video client connects to the video server, its available bandwidth can be detected using bandwidth detection method firstly, like that in [18].

The client classification is a typical problem of discriminant analysis. Since the goal of the proposed classification is to enable more video clients to access the video server simultaneously and improve the reconstructed video quality that the video clients receive under limited export bandwidth, the discriminant rule should satisfy the following two conditions: 1) the video clients with close available bandwidth should be classified into the same class and, 2) the bandwidth center of each class should have sufficient difference to each other. We choose the distance discriminant analysis [19] as the discriminant analysis methods and the Mahalanobis distance (MD) [20] as the discriminant rule to solve the video client classification problem. Note that the abovementioned two conditions can be appropriately described by the covariance and mean value of the bandwidth in one class. The covariance and mean value represent the degree of dispersion and the center of each class, respectively.

In statistics, the MD is based on the correlations between variables and measures the similarity of an unknown sample set to a known one. It outperforms the Euclidean distance by taking into consideration of the correlation of the data set and is scale-invariant. The MD of x to the class C_i can be calculated as follows.

$$D(x,C_i)=\sqrt{\frac{(x-\mu_i)^2}{\delta_i}} \tag{1}$$

where x is the new sample, which is the available bandwidth of the new joined client in our scheme. μ_i and δ_i are the mean value and covariance of the samples in the class C_i, respectively. In our client classification scheme, they represent the center and the degree of dispersion of the bandwidth of different video clients in one class. $D(x,C_i)$ is the Mahalanobis distance from x to C_i. The smaller the value of MD is, the higher the probability of x belongs to C_i.

In this paper, the discriminant function is formulated as:

$$W_{ij}=D^2(x,C_i)-D^2(x,C_j)=\frac{(x-\mu_i)^2}{\delta_i}-\frac{(x-\mu_j)^2}{\delta_j} \tag{2}$$

where W_{ij} represents the discriminant result, and $\delta_i\times\delta_j\neq 0$. If $i\neq j$ and $W_{ij}<0$, then $x\in C_i$; otherwise, if $i\neq j$ and $W_{ij}>0$, then $x\in C_j$; if $W_{ij}=0$, then x belongs to the class whose δ is bigger than the others, because δ indicates the dispersion degree of a class. The bigger δ is, the higher the dispersion degree is. If the new client x joins the class with bigger dispersion degree, the impact on the dispersion degree would be smaller. Otherwise the impact may be bigger. As shown in Fig. 1, the dispersion degree of Class J (denoted by squares) is bigger than that of Class I (denoted by circles). When a new client x (denoted by red dot) joins, if $W_{ij} = 0$, x would be classified into class J.

If $\delta_i \times \delta_j = 0$, we use (3) to classify clients,

$$W_{ij} = (x - \mu_i)^2 - (x - \mu_j)^2 \quad (3)$$

In (3), if $i \neq j$ and $W_{ij} < 0$, then $x \in C_i$; otherwise, if $i \neq j$ and $W_{ij} > 0$, then $x \in C_j$; if $W_{ij} = 0$, x belongs to the class whose $\delta = 0$.

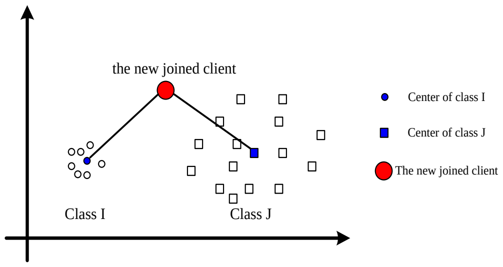


Figure 1. Client classification.

So far, we can classify the video clients into different classes according to their available bandwidth using the distance discriminant analysis. The problem now becomes: How many classes the video clients should be classified? The more classes the video clients are classified into, the more the requirements of different clients can be satisfied. But more classes also mean that more export bandwidth and more computational and storage resources of the video server are required. If the resources of the video server are not enough, they would become the bottlenecks of video transmission. On the contrary, if the video clients are classified into fewer classes, the export bandwidth and the other resources would be no longer the bottleneck, but the requirements of different video clients would not be fully satisfied.

Typically, the current network transmission links can be classified into three types according to the available bandwidth. The first type includes the links of broadband networks or those constructed or leased specially for video transmission, where the available bandwidth of more than 1Mbps can be usually guaranteed. The second type is that the links in public networks or some private networks are used to transmit many kinds of data, where the available bandwidth is usually around 200Kbps~600Kbps, such as the uplinks of ADSL. The third type is those low bandwidth links, like 2G/2.5G/3G wireless links, where the available bandwidth is usually around 30Kbps~150Kbps.

Considering the abovementioned practical heterogeneous network infrastructures, in this paper, we classify the video clients into three classes: the high-bandwidth class, the mid-bandwidth class and the low-bandwidth class. Corresponding to the three classes, the video server starts three video encoders: the high-bandwidth encoder, the mid-bandwidth encoder and the low-bandwidth encoder. If a video client connecting to the video server is classified into the high-bandwidth class, the high-bandwidth encoder would start to work to output higher-resolution (720×576) video streams to the video client. The mid-bandwidth encoder outputs lower-resolution (352×288) video streams to the video clients in the mid-bandwidth class. If the available bandwidth of a video client is relatively poor, the low-bandwidth encoder will be triggered to output mid-resolution but low-frame rate video streams to satisfy the requirements of the video clients.

III. Dynamic Bandwidth Allocation based on Greedy Algorithm and Client Classification

In the real-time video transmission, the reconstructed video quality provided to the clients need to be guaranteed [21], [22]. However, the available bandwidth of each client is usually different and limited under the complex and heterogeneous network infrastructures. Although in Section II, we use (2) and (3) to classify clients into three classes according to their available bandwidth, the reconstructed video quality would severely degrade if the limited export bandwidth of the video server cannot be allocated reasonably.

In [1], by analyzing the real-time video transmission techniques, two general approaches, network-centric approaches and end system-based approaches have been proposed. The network intermediate devices such as routers/switches are required to provide QoS support to guarantee bandwidth, bounded delay and packet loss for video applications for the network-centric approaches. But in most practical applications, we cannot access the network intermediate devices and impose any requirements on the network. So in this section, we propose an end system-based approach called dynamic bandwidth allocation based on greedy algorithm and client classification to maximize the overall reconstructed video quality to all video clients. This bandwidth allocation algorithm operates on the video server and does not impose any requirements on the network. Given the export bandwidth of the video server, we can allocate the export bandwidth to different classes reasonably, especially when the export bandwidth is limited. The encoders in the video server can adaptively adjust their output bitrates accordingly and send them to different video clients. This bandwidth allocation algorithm can efficiently utilize the limited bandwidth, thus improve the reconstructed video quality provided to the video clients.

In this paper, when some bandwidth is allocated to a class, the corresponding encoder will adjust its output bitrate to adapt to the allocated bandwidth, so we can regard the allocated bandwidth to a class as the output bitrate of the corresponding encoder. The Rate-Distortion (R-D) theory [23] gives the relationship between the output bitrate of the encoder and the distortion of the reconstructed video, as shown in Fig. 2.

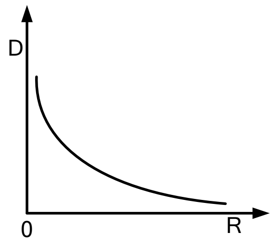


Figure 2. The R-D curve.

It also can be seen from Fig. 2 that the higher the bandwidth is allocated to a sequence, the smaller the distortion of the reconstructed video is, and vice versa. What is more, the less the bandwidth is, the bigger the improvement of reconstructed video quality is when the same amount of additional bandwidth is allocated.

In order to make the best use of the limited network bandwidth and provide better video quality to the video clients, we propose a bandwidth allocation algorithm based on greedy algorithm and client classification. The greedy algorithm is adopted to determine how many video clients can connect to the video server directly and how much bandwidth should be allocated to each class. The principle of the greedy bandwidth allocation is to enable higher bandwidth clients to connect to the video server directly, because the reconstructed video quality provided to the clients with higher bandwidth is better and the capture-to-display latency of direct-connected clients is smaller. During the video transmission, if there is still remaining bandwidth and the transmitted bitrates are lower than the available bandwidth of the classes, the classes would gain some remaining bandwidth to improve its received video quality. The principle of the remaining bandwidth allocation is to improve the reconstructed video quality as much as possible with the same amount of additional bandwidth. The proposed dynamic bandwidth allocation algorithm can be described as follows.

(1) Initialization.

Set the initial bandwidth center of each class for client classification at the beginning, denoted as B_h^{ini} , B_m^{ini} and B_l^{ini} , corresponding to the three types of heterogeneous transmission links. In this paper, we set that $B_h^{ini} = 1300Kbps$, $B_m^{ini} = 300Kbps$ and $B_l^{ini} = 50Kbps$. With more clients joining in and being classified into the classes, the bandwidth center can be updated as the average available bandwidth of clients in the class.

(2) Rough bandwidth allocation.

Determine the bandwidth that should be allocated to the high-bandwidth class, the mid-bandwidth class and the low-bandwidth class, denoted as B_h , B_m and B_l by the following formulas, respectively.

$$\begin{aligned} B_h &= \min_k\{B_h^k, B_h^{ini}\} \\ B_m &= \min_k\{B_m^k, B_m^{ini}\} \\ B_l &= \min_k\{B_l^k, B_l^{ini}\} \end{aligned} \tag{4}$$

where B_h^k , B_m^k and B_l^k are the available bandwidth of the k-th client in the high-bandwidth class, the mid-bandwidth class and the low-bandwidth class, respectively. We bound the allocated bandwidth to each class with the initial bandwidth, as in (4), to avoid that too much bandwidth might be allocated to the high bandwidth class and the clients in the low bandwidth class might get starved at the very beginning of the bandwidth allocation. Then the corresponding encoders adjust their output bitrates to adapt to the allocated bandwidth.

Determine the number of direct-connected video clients in the high-bandwidth class, $n_h = \min\{\frac{B_{total}}{B_h}, N_h, N_{total-h}\}$, where N_h denotes the maximal number of video clients in the high-bandwidth class that the video server allows to connect it directly, $N_{total-h}$ denotes the total number of video clients in the high-bandwidth class. B_{total} denotes the total export bandwidth of the video server. Then the number of direct-connected video clients in the mid-bandwidth class and low-bandwidth class can be determined as follows.

$$n_m = \min\{\frac{B_{total} - n_h B_h}{B_m}, N_m, N_{total-m}\} \tag{5}$$

$$n_l = \min\{\frac{B_{total} - n_h B_h - n_m B_m}{B_l}, N_l, N_{total-l}\} \tag{6}$$

where N_m and N_l denotes the maximal number of video clients in the mid-bandwidth class and low-bandwidth class that the video server allows to connect it directly, $N_{total-m}$ and $N_{total-l}$ denotes the total number of clients in the mid-bandwidth class and low-bandwidth class, respectively.

(3) Fine bandwidth allocation.

If the total bandwidth allocated to the direct-connected video clients is less than the export bandwidth of the video server, and the allocated bandwidth is lower than the available bandwidth of any video classes, fine bandwidth allocation will be conducted to reallocate the remaining bandwidth to the classes. According to the second principle mentioned above, different priorities are assigned to the video classes: the low-bandwidth class has the highest priority while the high-bandwidth class with the lowest. More specifically, two thresholds T_m and T_l are defined. When the remaining bandwidth is less than T_l , only the low-bandwidth class will be reallocated bandwidth. When the remaining bandwidth is more than T_l but less than T_m , it will be reallocated to the low-bandwidth class and the middle-bandwidth class rather than the high-bandwidth class. The remaining bandwidth will be reallocated to all the classes only when the remaining bandwidth is more than T_m . T_m and T_l can be determined according to the research results that an quality improvement would be visible to the human eyes only if it is more than 0.5dB in PSNR [24]. In this paper, T_m and T_l are set to be 150Kbps and 50Kbps.

After the fine bandwidth allocation, the output bitrates of the encoders for the three video classes can be adjusted accordingly to match the allocated bandwidth.

(4) Bandwidth allocation when a new client joins.

When a new client C_{new} joins, if there is sufficient bandwidth available for it besides those allocated to the direct-connected clients, C_{new} will be allowed to connect to the video server directly and the allocated bandwidth to other direct-connected clients remain unchanged.,

If the remaining bandwidth is not enough to allocate to C_{new} to make it connect to the video server directly, then:

If C_{new} belongs to the high-bandwidth class, and $n_h = N_{total-h}$ and $N_{total-h} < N_h$ and $N_{total-h} < \frac{B_{total}}{B_h}$, then the allocated bandwidth adjustment of all the three classes can be calculated as follows,

$$B_{total} - \alpha(n_h B_h + n_m B_m + n_l B_l) = \alpha B_h \tag{7}$$

$$\alpha = \frac{B_{total}}{(n_h+1)B_h + n_m B_m + n_l B_l} \tag{8}$$

where α is the adjustment factor.

If C_{new} belongs to the mid-bandwidth class, then

$$\alpha = \frac{B_{total}}{n_h B_h + (n_m+1)B_m + n_l B_l} \tag{9}$$

And if C_{new} belongs to the low-bandwidth class, then

$$\alpha = \frac{B_{total}}{n_h B_h + n_m B_m + (n_l+1)B_l} \tag{10}$$

To avoid severe fluctuation on the bitrate and thus the video quality, a threshold T_{adj} is introduced for α. In this paper, α is set to be 0.9. If $\alpha > T_{adj}$, then the allocated bandwidth of three classes would be adjusted as follows:

$$\begin{aligned} B_h &= B_h \cdot \alpha \\ B_m &= B_m \cdot \alpha \\ B_l &= B_l \cdot \alpha \end{aligned} \tag{11}$$

If $\alpha \le T_{adj}$ and C_{new} is not the first one in the high-bandwidth class, C_{new} would be specified as a forwarded client which will be discussed in Section IV in detail. If C_{new} is the first one in the high-bandwidth class, then some connected clients would be chosen to disconnect to save enough bandwidth to make C_{new} connect to the video server directly. The rule to choose the client to be disconnected can be determined according to different practical video applications. According to the two principles mentioned above, we assign different priorities to different video clients. The priority of the first client in a class is the highest, and then are the clients in the high-bandwidth class. The priorities of clients in the low-bandwidth class are the lowest. In such case, we disconnect the video clients with lower priorities.

(5) Bandwidth allocation when a current client disconnects.

If a direct-connected video client disconnects to the video server, then the bandwidth allocated to it would be reallocated to other classes as described in (3).

IV. Classification-based Multi-client Video Transmission

In this section, we first proposed a hybrid video transmission scheme by combining Unicast and forwarding, then the proposed Classification-based Multi-client Video Transmission algorithm is presented.

As mentioned above, the output bandwidth of the video server is often very limited. If all the video clients connect to the video server directly and obtain the video streams by Unicast, each video client might not get enough bandwidth to guarantee the reconstructed video quality. What's more, the more the video clients connect, the worse the provided reconstructed video quality will be.

To address this problem, we proposed a hybrid video transmission scheme by combining Unicast and forwarding. More specifically, when there is enough export bandwidth of the server to be allocated or when the adjustment factor $\alpha > T_{adj}$, more video clients will be regarded as direct-connected clients and allowed to connect to the video server directly, and the video server will transmit video streams to these clients by Unicast. But when the remaining bandwidth is not enough to be allocated and the adjustment of allocated bandwidth is bigger than the predefined threshold, i.e., $\alpha \le T_{adj}$, we choose limited video clients to connect to the video server directly as mentioned in Section III, and the others will be regarded as forwarded clients ($\alpha \le T_{adj}$ and C_{new} is not the first), who receive the video streams forwarded from the direct-connected clients in the same classes. The proposed hybrid transmission scheme can efficiently alleviate the pressure on the limited export bandwidth of the video server. It should be noted that the first client of all classes is directly connect to the video server in all cases.

It should be noted that in order to make the video server response faster, the forwarded video clients still send their feedbacks and interactive controls to the video server directly rather than forwarding, because the transmission display of direct-connected clients is smaller than that of forwarded clients. And if a forwarding client disconnects, the forwarded clients would reconnect to the video server automatically. The process of the reconnection is the same as shown in Algorithm 1.

V. Performance Evaluation

In this section, we first evaluate the performance of proposed bandwidth allocation in Subsection A. The performance of the proposed CMVT is then assessed in Subsection B.

The experiments are conducted on a practical video surveillance platform, with multiple clients demanding for the real-time captured and x264 coded video streams through a heterogeneous network connections. The initial bandwidth centers of the high-bandwidth class, mid-bandwidth class and low-bandwidth class are set to be 1300Kbps, 300Kbps and 50Kbps, respectively. The export bandwidth of the video server is set to be 2Mbps, and the video server buffer is set to be 1000K bits, half of the export bandwidth.

A. Performance of Proposed Bandwidth Allocation Algorithm

When multiple video clients with different available bandwidth connect to the video server, in order to evaluate the performance of the bandwidth allocation algorithm, each of the three classes has only one client.

The illustrative network topology is shown in Fig. 3, where VS denotes the video server, A, B and C represents the three video clients, of which the available bandwidth are detected as about 2MKbps, 500Kbps and 128Kbps, respectively.

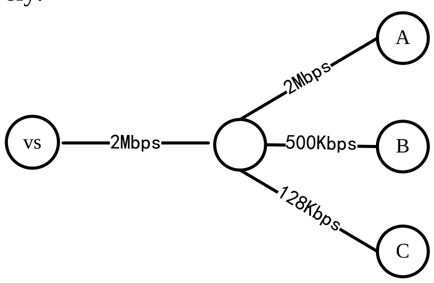
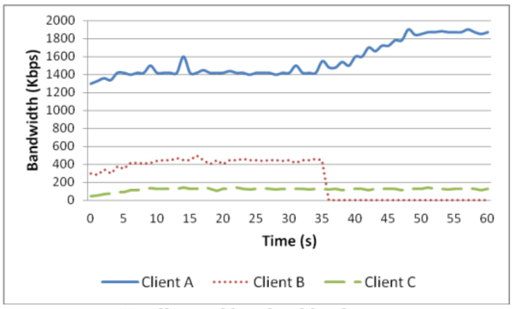
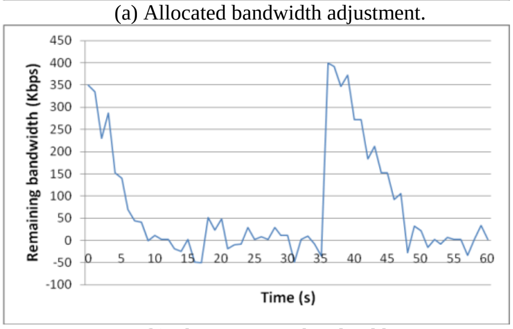


Figure 3. Clients A, B and C connect to the video server with different available bandwidth.



(a) Allocated bandwidth adjustment.



(b) The remaining bandwidth.

Figure 4. Bandwidth allocation by our proposed algorithm.

Based on the client classification, Clients A, B and C will be classified into the high-bandwidth, mid-bandwidth and low-bandwidth class, respectively. According to our proposed bandwidth allocation and video transmission schemes, these three clients will connect to the video server directly. The total bandwidth which has been allocated to the three video clients is 1650Kbps, less than 2Mbps. So the remaining 350Kbps bandwidth will be further allocated to the classes. The bandwidth allocated to the clients is shown in Fig. 4. From Fig. 4 (b), It can be seen that the remaining bandwidth is more than 150Kbps from time t=0 to t=5, so the bandwidth is allocated to all the three clients. After time t=5, the remaining bandwidth is less than 150Kbps and stops to be allocated to Client A, while Clients B and C are still allocated bandwidth. At time t=7, the remaining bandwidth is less than 50Kbps, which stops to be allocated to Client B either. At time t=10, because the bandwidth allocated to Client C has reached 128Kbps, the maximal available bandwidth of Client C in the low-bandwidth class, the remaining bandwidth is allocated to Client B again. At time t=37, Client B disconnects. The bandwidth allocated to Client B is available to be reallocated, so Client A gains additional bandwidth. The remaining bandwidth converges to around zero in a little more than 10 seconds, and the total export bandwidth of 2Mbps has fully and reasonably allocated to Clients A and C, which indicate that the proposed bandwidth allocation algorithm can adaptively adjust the optimal bandwidth allocation under dynamic networks connections and bandwidth conditions.

The performance of the M-LDLF algorithm proposed in [17] is also compared with our proposed scheme. In our experiment, three video encoders in the video server can be seen as three senders, and the export bandwidth of the video server can be seen as the shared resource. In M-LDLF, each client has a video encoder and the R-D models of the current frame are sent to the resource allocation module. However, it does not consider that if the same amount of additional bandwidth is allocated to an encoder, the improvement of reconstructed video quality would be much bigger when the available bandwidth of the corresponding client is lower. In our proposed bandwidth allocation, when the bandwidth is enough to allocate, each video client will gain additional bandwidth to improve its reconstructed video quality. But when the bandwidth is not enough, the bandwidth is allocated to the video clients in low-bandwidth class first to get the biggest improvement of reconstructed video quality by the same amount of remaining bandwidth.

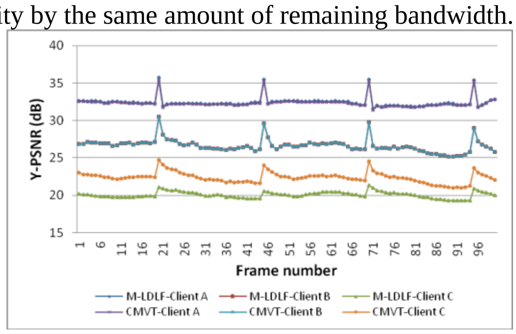


Figure 5. The Y-PSNR results of reconstructed video when using CMVT and M-LDLF.

Fig. 5 shows the objective quality (Y-PSNR) of reconstructed video provided to the video clients. The reconstructed video quality provided to Clients A and B are similar to each other using M-LDLF and our proposed scheme. While for Client C, compared with M-LDLF, the average value of Y-PSNR using our proposed scheme increases more than 2dB. This is because for the low-bandwidth class little additional bandwidth can improve the reconstructed video quality greatly, while for the high-bandwidth and mid-bandwidth classes the improvement of reconstructed video quality is negligible by allocating little additional bandwidth. In M-LDLF, three clients compete for the bandwidth all the time regardless of how much bandwidth remains, so Client C cannot get as much bandwidth as in our proposed algorithm for its video transmission, and its reconstructed video quality degrades unavoidably. The experiment results illustrate that our proposed bandwidth allocation algorithm can use the limited bandwidth more efficiently and provide better video quality to clients than M-LDLF.

B. Performance of Our Proposed CMVT Scheme

In this subsection, the experiments are conducted to verify our proposed CMVT scheme. Six Clients A, B, C, D, E and F with different available bandwidth connect to the video server simultaneously demanding for the real-time captured video. The detected available bandwidth of the six clients are 2Mbps, 1.9Mbps, 2Mbps, 500Kbps, 700Kbps, and 128Kbps, respectively.

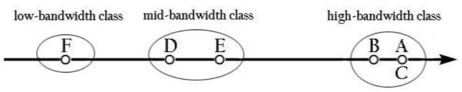
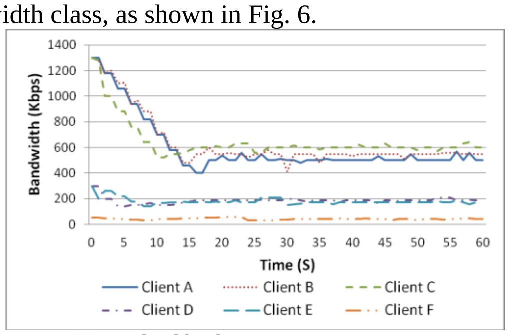
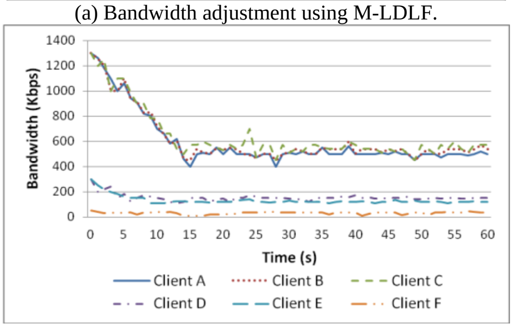


Figure 6. Clients classification results.

First, based on our proposed client classification scheme, six clients are classified into three classes. More specifically, Clients A, B and C are classified into the high-bandwidth class, D and E are classified into the mid-bandwidth class, and F is classified into the low-bandwidth class, as shown in Fig. 6.



(a) Bandwidth adjustment using M-LDLF.



(b) Bandwidth adjustment using Unicast.

Figure 7. Bandwidth adjustment using different transmission schemes.

Fig. 7 shows the adjustments of allocated bandwidth to six clients when using M-LDLF and Unicast. When using M-LDLF, all the six clients connect to the video server directly, and the video server has to send six video streams to satisfy the requirements of the clients. Although the bandwidth allocator can dynamically distribute the bandwidth to each client, each client can only be allocated much less bandwidth than its available bandwidth because of the limited export bandwidth. The video server has to decrease its output bitrates to enable the video streams to be transmitted under the allocated bandwidth, otherwise a large amount of video packets may be lost and the reconstructed video quality that provided to the clients will be poor. Similarly is the bandwidth adjustment using Unicast.

While in our proposed CMVT scheme, six clients are classified into three classes, only Clients A, D and F connect to the video server directly, and the video server specifies Client A as the forwarding client to forward video to Client B, then Client B forwards video to Client C, and Client D forwards video to Client E. The bandwidth adjustments using our proposed CMVT scheme is similar as shown in Fig. 4 (a), where the bandwidth of Clients A, B and C represents the bandwidth adjustment results of the high-bandwidth class, the mid-bandwidth class and the low-bandwidth class, respectively. The bandwidth adjustment curves of all the three classes increase at the beginning when using our proposed scheme, while using M-LDLF and Unicast the bandwidth adjustment curves decrease at the beginning. This is because the export bandwidth has to be allocated to all the six clients in M-LDLF and Unicast, while in our proposed scheme, the export bandwidth only needs to be allocated to three direct-connected clients, each video client will gain more bandwidth, so the reconstructed video quality provided to all the clients will be better.

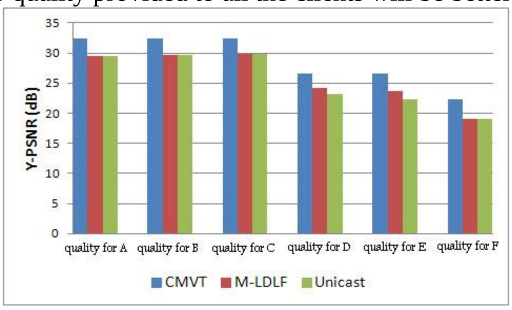


Figure 8. The reconstructed video quality for six video clients when using CMVT, M-LDLF and Unicast.

The comparison of reconstructed video quality (Y-PSNR) is shown in Fig. 8. As can be seen, the reconstructed video quality using our proposed video transmission scheme is much better than that using the other two algorithms for all the six video clients.

VI. CONCLUSIONS

In this paper, we have developed a client classification-based bandwidth allocation and video transmission scheme for multi-client video transmission over heterogeneous networks. Multiple video clients are first classified into different classes according to their detected available bandwidth using discriminant analysis, based on which the limited export bandwidth is allocated to different classes using greedy algorithm. The video streams are then transmitted to the clients using the proposed hybrid video transmission scheme. Extensive experimental results have shown that notable video quality improvements can be achieved for all the video clients with different available bandwidth.

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Bo Li received the B.S. degree in computer science from Chongqing University in 1986, the M.S. degree in computer science from Xi'an Jiaotong University in 1989, and the Ph.D. degree in computer science from Beihang University in 1993.

Now he is a professor of Computer Science and Engineering at Beihang University, the Director of Beijing Key Laboratory of Digital Media, and has published over 100 conference and journal papers in diversified research fields including digital video and image compression, video analysis and understanding, remote sensing image fusion and embedded digital image processor.

Peng Wang received the B.S. degree from Nanchang Hangkong University, China in 2004 and the M.S. degree from Shandong University, China in 2008, both in computer science and engineering. He is currently working toward the Ph.D. degree in the Department of Computer Science and Engineering at BeiHang University. His research interests are digital video compression and transmission.

Yongfei Zhang received the B.S. degree in Electrical Engineering and the Ph.D. degree in Pattern Recognition and Intelligent Systems from Beihang University, Beijing, China, in 2005 and 2011 respectively.

Since 2011, He has been an Assistant Professor with the Beijing Key Laboratory of Digital Media, School of Computer Science and Engineering, and the State Key Laboratory of Virtual Reality Technology and Systems, Beihang University. He was a visiting research scholar in Video Processing and Networking Lab, University of Missouri, Columbia, U.S, from 2007 to 2009. His current research interests include image/video processing, coding and networking, and video surveillance.