# Locality Awareness in Multi-Channel Peer-to-Peer Live Video Streaming Networks

Navid Bayat
Department of Computer Engineering
Sharif University of Technology
Email: bayat@kish.sharif.edu

Hamid R. Rabiee
Department of Computer Engineering
Sharif University of Technology
Email: rabiee@sharif.edu

Mostafa Salehi
Department of Computer Engineering
Sharif University of Technology
Email: mostafa_salehi@ce.sharif.edu

***Abstract*—The current multi-channel P2P video streaming architectures still suffer from several performance problems such as low Quality of Service (QoS) in unpopular channels. The P2P systems are inherently dynamic, and their performance problems could be categorized into four groups; peer churn, channel churn, uncooperative peers, and geographical distribution of peers. In this paper, for the first time, we develop a novel locality-incentive framework for multi-channel live video streaming. We propose a hierarchical overlay network architecture by utilizing a dual-mode locality-awareness method (spatial and temporal). Moreover, an incentive mechanism for encouraging peers to dedicate their upload bandwidth is introduced. Finally, an efficient buffer-map structure is proposed to predict the validation time of each video chunk request as well as the receiving time of video chunks. We have evaluated the performance of our framework via extensive simulations and compared it with the state-of-the-art method in multi-channel systems. The simulation results demonstrate that the quality of unpopular channels is improved by up to 38%. Moreover, the proposed method improved the quality of video by reducing the playback delay (up to 27%), distortion (up to 39%), and reducing the redundant traffic into the Internet backbones (up to 43%).**

## I. Introduction

Currently, large-scale commercial Peer-to-Peer (P2P) networks such as Coolstreaming [23] and PPLive [16] are extensively used for live video streaming. Almost in all these systems, multiple channels broadcast video to thousands of users, simultaneously [5]. Therefore, in these P2P video streaming systems the peers could participate in more than one channel and switch between them.

To provide higher video quality and lower implementation costs in multi-channel live video streaming architectures, the following issues must be considered; 1)Time Constraint: in live video streaming systems, the architecture imposes time constraints on video chunks transmission (specifically, video chunks arriving at receiver after playing time deadlines are not useful anymore [13]), 2)Small Size Channels: in the channels with a small number of participating peers, the quality of video is not satisfactory [5], and 3)Traffic Redundancy: since the peers are geographically distributed, the communication between them imposes huge redundant traffic into the Internet. Thus, it is very critical to reduce the redundant video traffic in the Internet backbones [10].

Recently, there have been some efforts to solve the first two problems (Time Constrain and Small Size Channels) [19][20][21][8]. In [19], the authors study the problem of provisioning the server bandwidth consumption in multi-channel systems. Wu et al. [20][8] proposed the View-Upload-Decoupling (VUD) approach to minimize the influence of channel churn among multiple channels. Moreover, in [21], the same authors used queuing network models to analytically study the performance of multi-channel systems by considering channel churn, peer churn, and bandwidth heterogeneity. Most of these works are focused on cross-channel resource sharing by utilizing the surplus upload bandwidth of some channels to improve the quality of video in other channels.

However, to the best of our knowledge, there is no work that addresses the third problem (Traffic Redundancy). One of the approaches to solve this problem is to utilize the locality-aware algorithms [15] for optimizing the neighbor selection policy. Locality-awareness means that the peers join to other nearest peers in the overlay network. The measure of selecting nearest peers could be various metrics such as delay, bandwidth, and underlay distance between two peers [2]. There may be slight differences between the scheme proposed by the CHS and previous ones. Locality awareness and structuring of incentives to encourage cooperation are topics that have been proposed and studied before [22]. We will discuss carefully of how the paper's contributions differ and improve on earlier works such as P4P [22].

In this paper, we propose a novel framework for multi-channel P2P live video streaming, which we refer to as Cascading Hierarchical Streaming (CHS). CHS introduces a hierarchical overlay network by utilizing dual-mode (Spatial and Temporal) locality-aware algorithms (refer to Fig. 1). The overlay network of the proposed framework composed of four different levels that are defined based on the temporal distance of peers from the camera (video source), and the amount of dedicated upload bandwidth. The idea of introducing these levels is to encourage the peers to dedicate more upload bandwidth and allow them to find their neighbors in upper levels. In each level, there are some trackers which keep the list of peers in that level. These trackers are being selected among the peers.

We evaluate the performance of CHS via extensive simulations and compare it with the VUD method as the state-of-the-art solution for multi-channel systems. Our results shows the proposed framework reduces redundant traffic between Au-

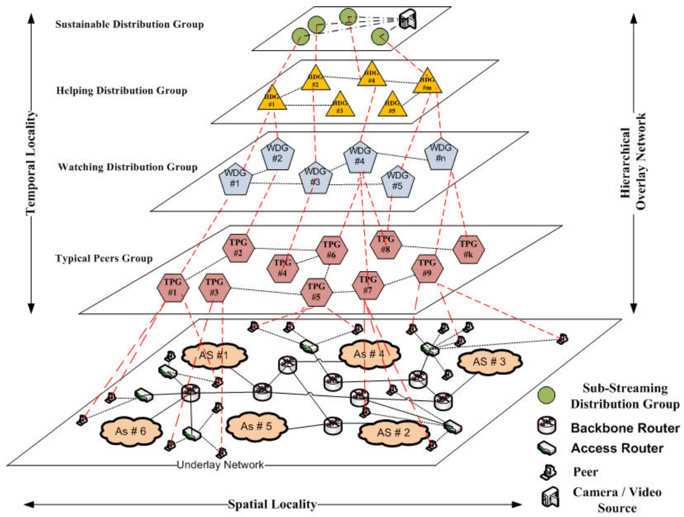



Fig. 1: Hierarchical Overlay Network

tonomous Systems (ASs), measured by the link stress metric, by about 43% in average. Since the peers in the same AS have shorter distance in underlay network compared to the cross AS, neighbor selection inside the AS (by using dual-mode locality-awarness) leads to lower link stress. Furthermore, the simulation results demonstrates that the video quality of unpopular channels (small size channels) is improved in terms of distortion (38% in average). Moreover, quality of video in the whole system (all popular and unpopular channels) is improved in terms of playback delay (27% in average) and distortion (39% in average), because the proposed predication method decreases the packet loss by considering the frame timeout.

In summary, the contributions of this paper are as follows:

- CHS is the first multi-channel P2P live video streaming framework that considers the locality concept for constructing the overlay network. The proposed locality-aware algorithm uses both spatial and temporal distance properties of the peers' connections.
- An incentive mechanism is proposed that encourages the peers to dedicate their upload bandwidth to other channels. Since the quality of video at the peer side is related to its upload rate, it is very important to implement an incentive scheme for better streaming services. Without this mechanism, the locality-aware techniques do not provide any advantages for ISPs and peers.
- A new buffer-map structure is proposed to enhance video quality by reducing the end-to-end delay. This buffer-map includes four types of information; 1) Availability of the frames in the buffer, 2) Size of each frame in the buffer, 3) Estimation of response time, and 4) Average amount of free upload bandwidth.
- A new mechanism is proposed to predict the chuck arrival time in the peer's buffer by considering the conditions (upload bandwidth and busy time) of the peer's neighbors.

The remainder of this paper is organized as follow. Section II briefly summarizes the previous work. The detailed design of the proposed framework is presented in section III. In section IV, the performance evaluation of the proposed method is provided. Finally, we conclude the paper in Section V.

## II. Related Work

In spite of considerable recent research on improvement of isolated-channel P2P video streaming architecture [5][2], little attention has been paid to study multi-channel P2P streaming systems [19][20][21][8]. Moreover, measurement studies [5] have shown that the resource distribution (total upload bandwidth) is unbalanced among different channels in multi-channels network.

The multi-channel design techniques can be classified into three groups [18]; (1) Naive Bandwidth allocation Approach (NBA): This is the simplest design for implementing multi-channel systems. In NBA, a peer subscribes only to its watched channels, and dedicates its upload bandwidth to them. (2) Passive Channel-aware bandwidth allocation Approach (PCA): In PCA, a peer joins only to its watched channels, and optimally dedicates its upload bandwidth to them. (3) Active Channel-aware bandwidth allocation Approach (ACA): In ACA, a peer joins not only to its watched channels, but also to some other channels as a supporter. The main idea in ACA is to allow the channels with surplus upload bandwidth help those with deficit upload bandwidth. Because the upload bandwidth is an important resource that greatly influences the quality of live video.

As an example of ACA, View-Upload-Decoupling (VUD) [20] is the state-of-the-art framework for multi-channel live video streaming. VUD provides cross-channel resource sharing. In VUD, each peer is assigned to one or more channels as a supporter. For each assigned channel, the peers help to distribute the channel. However, it still suffers from important issues such as upload bandwidth overhead and distribution swarm management cost. Liang et al. [8] have proposed a partial decoupling strategy instead of a complete decoupling of viewing and uploading of a peer in multiple channels. None of the above work proposed a mechanism to motivate the peers to share their upload bandwidth.

While multi-channel P2P video streaming networks have achieved promising results, they have several drawbacks. There are a large number of unnecessary traverse links within a provider network which causes a huge number of cross Internet Service Provider (ISPs) traffic[7]. The studies in [7] showed that $50\% - 90\%$ of the existing local content in peers are downloaded from external sources. Moreover, the authors in [4] have shown that despite the availability of contents from peers inside the same LAN, about $82\%$ of the video chunks are fetched from peers outside the LAN (for example, percentages grow to $90\%$ for PPLive). Most of the current P2P networks assume that all peers are willing to contribute their resources [21]. However, this assumption may not be true because peers in the decentralized P2P networks restraint to allocate their resource to other peers [24].

In summary, most of previous research efforts have focused on improving the quality of video in channels with low number of participant peers by using the surplus upload bandwidth of other channels. Since the peers are geographically distributed, the communication between them imposes huge redundant traffic into the Internet. Thus, it is very critical to reduce the redundant video traffic in the Internet backbones [10]. One approach to solve this problem is to utilize the locality-aware algorithms [15] for optimizing the neighbor selection policy. But, in this work we consider the concept of locality in overlay network construction to reduce the redundant traffic which may be generated by P2P video streaming systems in the Internet. Furthermore, live video streaming has some critical factors which should be taken into account [4].The goal of this paper is to propose an efficient architecture in terms of self-management, decentralized management, complexity, and effectiveness.

We can categorize the previous related work that consider locality in P2P networks as follows. (1) ISP locality driven methods [7][9]: here, the interconnected network between ISPs has been considered as the main criteria. (2) Infrastructure based methods such as Content Delivery Networks (CDNs) [24]: CDN technology is exploited to reduce cross network traffic cost by using the proper DNS resolution. (3) Bootstrap or Tracker based methods [6]: Bootstrapping can be used to find the appropriate places for joining new peers to the network. Tracker nodes maintain a list of all active peers in the network. Bootstrap or tracker scenarios in the P2P networks can lead to single point of failure. (4) Client side based methods such as Time To Live (TTL), and Round Trip Times (RTT) [10]: By TTL, we can measure the underlay hop count distance and the peers can find their neighbors that are geographically closer to them. Moreover, by RTT, we can measure the delay between two peers. Therefore, the peers can find their neighbors which have shorter response time.

It it worthwhile to mention that we implement locality-awareness alongside the incentive mechanism for live video streaming. Thus, we need to consider trade-off between the cost and complexity. Furthermore, CHS has no overhead in the underlay network compared to the other incentive mechanisms.

## III. Proposed Framework

In this section, the proposed framework which we refer to as Cascading Hierarchical Streaming (CHS), is introduced. Fig. 2 shows the block diagram of CHS. This framework is composed of three major parts; 1) Hierarchical Overlay Construction, 2) Incentive Mechanism, and 3) Live Video Distribution. The first part introduces a hierarchical overlay network by utilizing a dual-mode (Spatial and Temporal) locality-aware algorithm. The overlay network includes four different levels that are defined based on the temporal distance of peers from the camera (video source) and the amount of dedicated upload bandwidth. The idea of introducing these levels is to encourage the peers to allocate more upload bandwidth to the system and let peers to find their neighbors in the upper level. Second part proposes an incentive mechanism which consists of local

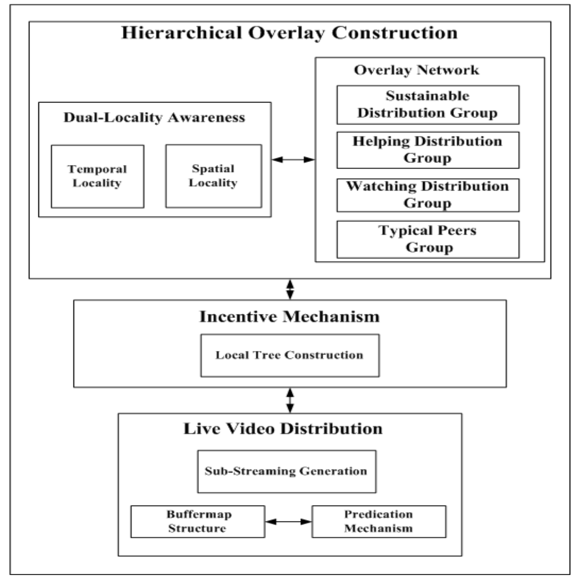



Fig. 2: CHS Framework

tree construction. In the third part, live video distribution is introduced which includes sub-stream generation, new buffer-map structure, and a prediction mechanism. In the following, we discuss each part in details.

### A. *Hierarchical Overlay Construction*

CHS introduces a hierarchical overlay for P2P networks which consists of some distribution groups in each level. We define three types of distribution groups: (1) Watching Distribution Groups (WDG), (2) Helping Distribution Groups (HDG), and (3) Sustainable Distribution Groups (SDG). An example of hierarchical overlay construction has been shown in Fig. 1. In CHS, each peer has a distribution matrix that presents the distribution groups it joins to. In the Watching Distribution Level (WDL), the peers are responsible for dedicating their upload bandwidth to their own watching channel, and they could join to the local tree which has been created in WDG. In the Helping Distribution Level (HDL), the peers are responsible for dedicating their upload bandwidth to other channels as supporter, and become more closer to the camera (video source) in terms of time distance. In the uppermost level of this overlay architecture, camera divides the video stream into $k$ number of sub-streams and push it to $k$ peers (thus creating a sustainable group). It means that upper levels have lower distances from camera (video source) in terms of time.

**Local Tracker:** In CHS, some peers act as local trackers and keep the active peers in a local area. It means that each local tracker retains the list of peers which are close to it in terms of underlay hop count. CHS utilizes two concepts of locality for neighbor selection; (1) Spatial Locality, and (2) Temporal Locality. In CHS, a local tracker has three types of duty. First, similar to Content Distribution Networks (CDNs), it gets a video sub-stream from camera and uploads it for other trackers. Second, it maintains the list of active peers locally. Third, it detects the peer churn.

Local trackers in CHS keep the address of peers in the underlay network which are in the distance of $r$ from them. Therefore, we assume that each local tracker is the center of a circle with radius $r = max(D_u^{i,LT})$, where $D_u^{i,LT}$ is the underlay distance between peers $i$, and Local Tracker (LT). Therefore, the maximum distance between two peers in the underlay network could be $2r$

Each level in the hierarchical overlay has boundaries proportional to the dedicated upload bandwidth (minimum and maximum boundaries). For each level, we have some Local Level Trackers (LLT) which retain the list of active peers in that layer. If one peer joins to a level but it does not support the minimum upload bandwidth to its neighbors, then its neighbors send notification message to the LLT and disconnect from it.

**Spatial Locality:** For neighbor selection in spatial locality, each peer uses the concept of stretch. This metric corresponds to the overlay and underlay network mismatching. More specifically, it shows how much the length of a shortest route between two nodes in overlay is away from a shortest route between them in the underlay network. Let $D_i$ be the number of overlay hop between two nodes in the overlay network, and $d_i$ be the number of IP path hop for two nodes which directly use the underlay network for communication. Then, the stretch factor is defined as $ST_i = \frac{D_i}{d_i}$.

In CHS, when peer $i$ receives the lists of peers from some local trackers, it sends its request messages to the peers in those lists. In each message, peer $i$ sends a request to the target peer to determine its distances from camera (video source) in the overlay, and underlay networks. Moreover, peer $i$ should calculate the underlay distance between itself and the peers in those lists. It is clear that the distance from peer $i$ to those peers is one hop in the overlay network. Finally, each peer should calculate its average stretch from itself to camera by using Equ. 1.

$$Avg_{stretch} = \frac{\sum_{i=1}^{w} ST_i}{w} \tag{1}$$

Where $w = \frac{BW_{upload}}{Avg_{VBR}}$ and $BW_{upload}$ is the upload bandwidth of a peer, and $Avg_{VBR}$ is the average video bit rate. Our objective in the spatial locality is to minimize the $Avg_{stretch}$ in Equ. 1 by an efficient neighbor selection. Therefore, there are many combination for neighbor selection in Spatial Locality, and we could reduce the number of underlay routers and overlay peers in the traverse path of video packet from camera to each peer. It is obvious that when the numerator of Equ. 1 decreases, then the $Avg_{stretch}$ decreases as well. Therefore, Spatial Locality selects the neighbor with minimum $\frac{D_i}{d_i}$, in which $d_i$ is based on the user connection in the network (i.e. Internet).

**Temporal Locality:** In temporal locality, each peer should calculate its Average Stretch Latency (ASL), and thus minimizing network latency and bandwidth consumption. Stretch Latency (SL) is defined as the ratio of delay experienced when sending data using the overlay to the delay experienced when the same data is sent directly by using the underlay network [11]. Each peer should be aware about its neighbor stretch latency for calculating the ASL. To decrease the effect of instance changes in video rate, we define a controlling coefficient $\gamma = \frac{BW_F^U}{BW_T^U}$ where $BW_F^U$ and $BW_T^U$ represents the free and total upload bandwidth of a peer, respectively. It means that when the video bit rate is changed instantly, the impact of Instance Increment of Stretch Latency (IISL) should be reduced for computing the ASL (refere to Equ. 2). This latency depends on the free upload bandwidth of peer. When video bit rate increases, it consumes more capacity of upload bandwidth of the peers to respond to the video request messages.

$$IISL = \frac{(1-\gamma) \times ASL + \gamma \times SL}{2} \tag{2}$$

Moreover, new peers should calculate the Local End-to-End Delay (LEED) between itself and the list of peers which it receives from the local trackers. Therefore, the new comers should go through two steps to select their neighbors; (1) They sort the list of peers in terms of IISL, and (2) They select their neighbors which have the lower LEED and send join requests to them.

### *B. Incentive Mechanism*

Since the quality of video at the peer side is related to its upload rate, it is very important to implement an incentive mechanism for live video streaming. The main cause of degradation of fault-tolerance, scalability, and content availability in the P2P systems is the free rider. Free riders in the P2P networks are peers that only use services but provide little or nothing in return. Therefore, it is very important to encourage the peers to act as supporter and allocate their upload bandwidth for other channels. Algorithm 1 shows the incentive mechanism in CHS. CHS enables cross-channel resource sharing which means that some peers could subscribe to more than one channel at the same time.

**Tree Construction:** The hight of CHS overlay shows the locality in terms of delay (from camera). Moreover, this framework constructs the tree architecture for encouraging peers to share a portion of their upload bandwidth. For each camera, we construct the sub-streaming tree. It means that for each sub-stream of video, CHS creates one tree. Those peers which contribute more upload bandwidth are permitted to join these trees.

### *C. Live Video Distribution*

In the proposed framework, video source divides a stream of video into some sub-streams to alleviate the upload overhead. A video source directly connects to some of local trackers and upload video sub-stream for them by using a push mechanism. Since there are many local trackers in the network, the video source should select some of them for pushing the sub-stream (SDG formation). In CHS, each peer could measure the potential of its neighbors in the past and estimate their potential for supporting video content in the near future.

**Algorithm 1** *Inventive Mechanism Alghorithm*

**Input** :
$DUBW$: Dedicated Upload Bandwidth
$STL$: Super Tracker in each Level
$VTR$: Validation Time for Request
$\lambda$: Coefficient for Evaluation Time
**Output** :
$RS$: Resource Sharing
———————————

```
Time Slot t = k
while λk<t do
  if 10% VTR is reached then
    send Notification Message To STL
    send Disconnect Message
    change Its Connection Level To Lower Level
  else
    if Peer has DUBW for allocating Other Channels then
      change Its Connection Level To Upper Level
    end if
    if Peer has DUBW for allocating its Wacthing Channel then
      joining to Local Tree in Distribution Groups
    end if
  end if
end while
```

**buffer-map Structure:** A buffer-map indicates which video chunks currently exist in the player buffer of peer. CHS proposes a new type of buffer-map structure to enhance video quality by reducing the end-to-end delay. This buffer-map includes four types of information; 1) Availability of the frames in the buffer, 2) Size of each frame in the buffer, 3) Estimation of response time, and 4) Average amount of free upload bandwidth.

By utilizing the buffer-map, the peers estimate the time difference between the current time and the deadline of a chunk which we call it "urgent factor". Let the video chunk consists of $l$ frames divided into $c$ chunks, and $f$ represents the frame rate of video (frame per second). Therefore, each chunk has the $\frac{c}{f}$ seconds of video. Moreover, the playback time of $n$-th chunk can be computed as $(n-1)\frac{l}{f}$. Let $S_n$ be the size of $n$-th chunk in $Kb$, and $T_{ij}$ be the transmission time between two peers $i$ and $j$, and $BW_i^u$ be the upload bandwidth of peer $i$. Then, the $n$-th chunk should be delivered in time $T_{ij} + \frac{S_n}{BW_i^u} \leq (n-1)\frac{l}{f}$. Equ. 3 shows that the average busy time for each neighbor of a peer.

$$T_{avg} = \frac{(1-\gamma)T_{avg} + \gamma T}{2} \tag{3}$$

Where $T_{avg}$ is the average response time of that neighbor, and $T$ is the necessary time for responding to a request by that neighbor in the last buffer-map exchange. We define $T$ as follows.

$$T = \frac{S_i}{BW_i^u} + \frac{S_j}{BW_j^d} + T_{ij} \tag{4}$$

Where $BW_i^d$ is the download bandwidth of peer $i$.

**Prediction Mechanism:** In CHS, we propose a new mechanism to predict the chuck arrival time in the peer's buffer by considering the conditions (upload bandwidth and busy time) of the peer's neighbors. The peers send their requests to one of their neighbors based on the predicted time of each chunk.

In summary, each peer should estimate the service time of its neighbors. Let $t_s^q$ be the service time of the $q$-th neighbor of peer $s$ that can be defined as follows:

$$t_s^q = \frac{\sum_i G_i}{BW_i^u} \tag{5}$$

Where $G_i$ is the size of request $i$ in the queue, and $BW_i^u$ is the upload bandwidth of this neighbor.

In addition, we can calculate the playing time of each chunk of peer $s$. If we assume that each chunk has $k$ number of frames, and $f$ be the video frame rate (frame per second), then each chunk has the $\frac{k}{f}$ seconds of video. The playback time of $m$-th chunk can be computed as $(m-1)\frac{k}{f}$. Therefore, by assuming that the chunk number starts from 1, the frame numbers in the range of $((m-1)k+1, mk)$ are in the player buffer before playing time of $m$-th chunk.

Next, peer $s$ should compute the validation times of the frame requests to its neighbors. The video frames captured by a camera (video source) can be encoded to three types of video frames (I, P and B) in application layer. The video frame have different importance for the overall quality. Since other P and B frames depend on I frames, I frames are the most important among all three frame types. Therefore, we don't consider validation time for requests of $I$ frames. Then, peer $s$ sets a timer for its P or B frames requests and when each of the timers reach zero, it sends that request to another neighbor. We define validation time for each neighbor as follows:

$$V = T + \frac{(1-\gamma)T_{avg} + \gamma T}{2} \tag{6}$$

Peer $s$ predicts the validation times of all neighbors by using the above method, and then decides to send its requests to the neighbors.

### *D. Controlling Message*

In CHS, there are three types of controlling messages; (1) Neighbor Selection Controlling Message: Since we have two types of locality-aware algorithms for constructing the hierarchical overlay, it causes more controlling messages to neighbor selection compared to the random selection, (2) Requesting message (for video chunks): As we mentioned, CHS uses a prediction mechanism to reduce the video packet loss. This mechanism utilizes more requesting messages to control the timeout of the video chunks in the player, (3) Incentive Mechanism Controlling message: The architecture of CHS is fully decentralized.

## IV. Performance Evaluation

### *A. Simulation Methodology*

For simulation, we use OMNeT++.4.1 [12] that is a modular and discrete event tool for simulating communication networks. We also use the INET framework [17] for creating TCP/IP network. This framework implements UDP, IP, and

Data Link Layer in OMNeT++. With OverSim [1], a framework in OMNeT++ for simulating P2P systems, we construct the P2P overlay network. It utilizes the INET framework for simulating the underlay layers. In general, OverSim prepares a reusable framework that has two main parts; (1) Overlay layer: for creating neighbor relation and constructing the mesh (tree or structured systems), and (2) Application layer.

In our simulations, the underlay topology is generated by using Georgia Tech Internet Topology Model (GT-ITM) [3] tools for OMNeT++ v.4. This network is a decentralized and unstructured P2P network with 28 backbone routers and 748 access routers. The peers in overlay network select a router randomly and connect to them by selecting random underlay link with bandwidth between 128 Kbps to 2 Mbps and delays between 15 ms to 156 ms. In this simulation, we use the video trace files from the Video Trace Library in [14] for streaming actual video. We assume that the size of a chunk equals to 1 video frame. Therefore, the unit of transferring in our network is video frame.

Our framework consists of two important elements: (1) Network Manager, and (2) Local trackers. Network manager has the role of manager in the multi-channel video streaming network. As mentioned in [20], multi-channel networks need to periodically compute the resource index of channels and send notification messages to peers in rich-upload bandwidth channels for improving the QoS in unpopular channel and overcome the negative influence of channel churn. We compare the proposed framework with View Upload Decoupling (VUD) as the state-of-the-art mechanism for multi-channel P2P systems. Our framework has two modes; CHS prediction mode, and CHS without-prediction mode.

### *B. Evaluation Results*

**Link Stress:** Link stress [10] measures the number of replicated video packets that enters an AS until all peers in that AS receive those packets. The lowest value is 1 which means that only one packet enters into an AS, and all peers in that AS receive that packet. The maximum number of link stress is $N$ which is the number of peers in the AS. As Fig. 3 shows we can safely reduce (43% in average) redundant traffic by considering the underlay hop count in neighbor selection, since there is no difference in graph construction between CHS-Prediction and CHS-Without prediction. In CHS, peers selecting their neighbors by using dual-mode locality awareness, and implicitly consider the underlay distance between themselves and other peers in the network. As a result, they establish the connection with those peers with shorter distance in the underlay. As we know, the peers in the same AS have the shorter distance in underlay network. Therefore, neighbor selection inside the AS, instead of cross AS, can reduce the link stress.

**Stretch:** The ratio between overlay and IP path hop count is called stretch [10]. It shows how much the length of a shortest path between two nodes in overlay network is different from the length of a shortest path between them in the underlay network. A lower stretch results in a better query time and

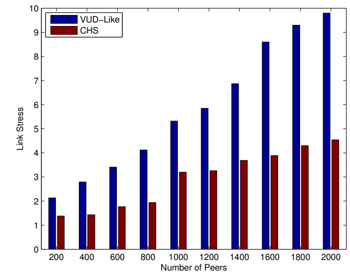



Fig. 3: Link Stress

reduces unnecessary bandwidth consumption [10]. Moreover, this parameter shows the mismatching between overlay and underlay networks. As Fig. 4 shows, CHS reduces the stretch factor in the P2P network. Since, CHS considers the stretch factor for neighbor selection, and this can reduce both the number of underlay and overlay hop counts. As Equ.1 shows the number of underlay hop count is taken into account when a peer decides to select its neighbors. Therefore, it reduce the average stretch.

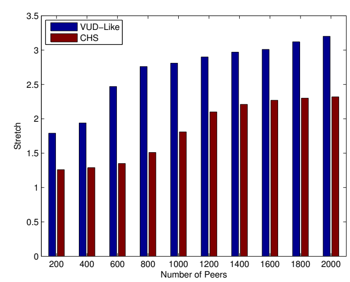


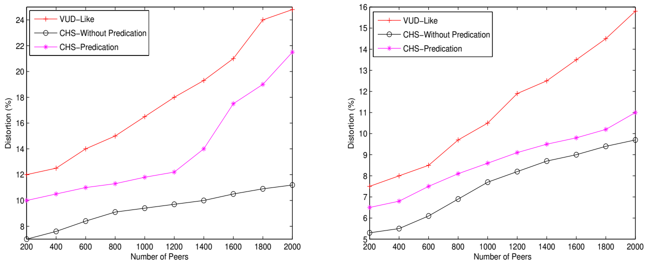

Fig. 4: Stretch

**Distortion:** Distortion or video packet miss ratio is an performance metric for each channel in the P2P multi-channel network. It is the percentage of video content which is lost compared to the original video. Equ. 7 shows how we calculate the distortion. It shows the quality of video that the network can guarantee for their peers. Moreover, as Fig. 5 shows, by increasing the number of peers in the network, the growth of distortion rate is becoming very low. It also shows that by increasing the number of peers in the network the number of video sources increases as well.

$$Distortion = \frac{(\textit{Total Size of Received Frames}) \times 100}{\textit{Total Size of Requested Frames}} \quad (7)$$

Distortion rate consists of two parts; (1) Packet loss due to the loss in the underlay links, and (2) Loss from frame timeout. Since the underlay network for all algorithms is the same, the loss due to the physical link is the same for all algorithm in the framework.

As we can see in Fig. 5, when the startup buffer increases, video distortion decreases (44% in average). When the start up buffer increases, peers have more time to get the video frame from their neighbors, and the distortion is lower than

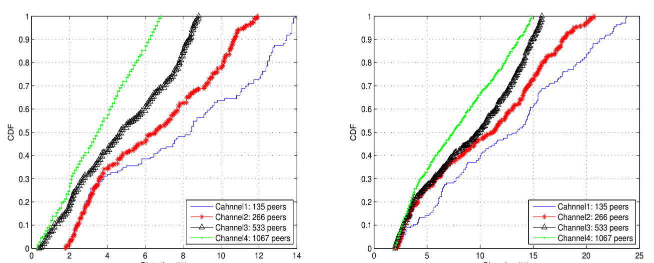



(a) Startup Buffer 10 (b) Startup Buffer 20

Fig. 5: Average Distortion

when the start up buffer is set to 10 seconds. Moreover, the rate of distortion reduces in CHS-prediction mode (39% in average). CHS-Prediction has the minimum distortion because by using the prediction method, we reduce the packet loss due to the frame timeout. Furthermore, CHS-Without prediction has the lower distortion rate than VUD, because it exploits the temporal locality-awareness and the incentive mechanism.

Fig. 6 shows the CDF diagram of average distortion in each of four channels (defined in the simulation scenario) for multi-channel and isolated-channel systems. It shows when the number of peers in a channel increases, the distortion of the whole channels decreases (38% in average). By comparing Fig. 6.a and Fig. 6.b we can conclude that encouraging the peers to allocate their surplus bandwidth for channels with low number of peers, increases the video quality in the multi-channel systems.

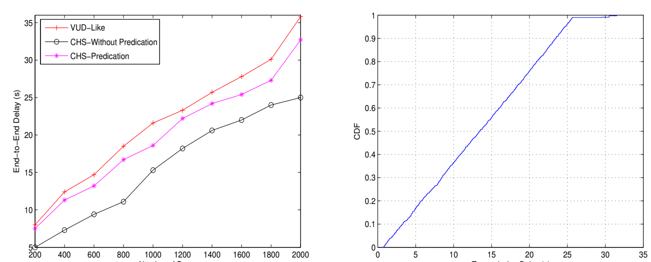



(a) CHS-Predication Channels-Startup Buffer 10 (b) Isolated Channels-Startup Buffer 10

Fig. 6: Distortion of Each Channel

CHS leads to better perceived video quality in the channels with low number of participants peers. We can consider two facts for justification. First, in CHS we utilize the dual mode locality awareness which causes to form incentive mechanism and encourage peers to upload their surplus bandwidth for other channel and also reduces the video packet loss. Second, we change the buffer-map structure of peers. Furthermore, we implement the prediction mechanism which leads to reduction in frame loss due to frame late arrival.

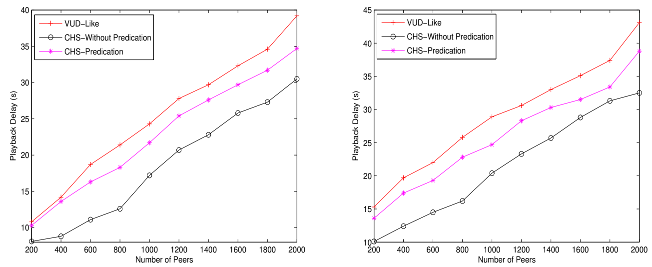
**End-to-End Delay:** Average end-to-end delay is defined as the average time between transmission and arrival of data packets from source to destination. End-to-end delay has a significant effect on real-time video streaming. As Fig. 7.a shows CHS reduces the average end-to-end delay (23% in average) due to its neighbor selection mechanism. It is clear that when the peers try to find their neighbors in terms of delay, the total latency in the network decreases. Since the peers find their neighbors with minimum underlay and overlay hop counts, it can implicitly reduce the time for traversing video packets in the network. As mentioned before, two factors are considered for neighbor selection in CHS. In spatial locality, we try to reduce the number of hop count in both overlay and underlay. Therefore, the number of hop between two peers reduces as well and cause to reduce the time for video packet transmission, as well. In temporal locality, the peers try to find their closer neighbors in terms of delay. Our results show that CHS-Prediction has the lowest end-to-end delay because it utilizes the prediction mechanism. In prediction mechanism, the peers estimate the average busy time of their neighbors and send their requests to those neighbors which have lower busy time. Fig.7.b shows the video packet transmission time in the underlay network for a selected peer which is far from the camera (video source) in terms of underlay hop. Fig.7.b demonstrates that the geographical distance from the video source and the peers can cause long playback lag in the peer side. As we can see, about 50% of the video packets have the underlay delay of less that 15 seconds.




(a) Average End-to-End Delay (s) (b) Transmission Delay (s)

Fig. 7: Average Playback Delay

**Playback Delay:** Playback delay or start up latency in live video streaming is the difference of video time stamps between source node and playing time in the destination peer, and it shows the time taken to fill the player buffer of the peers by considering they startup buffering time. This metric also increases as the size of network grows. As Fig. 8 shows, the prediction mechanism for live video streaming could enhance the playback delay of the systems by reducing (27% in average) the delay of filling the player buffer in the peers. It shows that when startup buffer increases, the peers have more time to receive video frames form their neighbors. Moreover, we can conclude that when the number of peers increases, the number of video sources in the network increases as well.




(a) Startup Buffer 10 (b) Startup Buffer 20

Fig. 8: Average Playback Delay

## V. Conclusion

In this paper, we proposed a novel framework for multi-channel P2P live video streaming that uses dual-mode (Spatial and Temporal) locality-aware algorithms for efficient neighbor selection. This is the first multi-channel P2P live video streaming architecture that considers the locality concept for constructing overlay network. Moreover, we proposed an incentive mechanism that encourages the peers to share their upload bandwidth between different channels. Furthermore, we introduced a new buffer-map structure to enhance video quality by reducing the end-to-end delay. In addition, we proposed a new mechanism to predict the chuck arrival time in the peer's buffer. We evaluated the performance of the framework via extensive simulations and compared it with VUD approach. Our results demonstrated that the redundant traffic between ASs decreases significantly due to neighbor selection inside the AS. Furthermore, we found that the video quality of unpopular channels and whole system can be improved in terms of playback delay and distortion (27% and 39% on average, respectively).

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