Delivering Scalable Video Coding using P2P Small-World based Push-Pull Mechanism

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Abstract—**Peer-to-Peer (P2P) networks have proven to enable large-scale content distribution over the Internet thanks to peers organization in overlays. However, real-time content delivery such as live and video on demand (VoD) streaming applications requires significant consideration in term of peer organization to provide concurrent users with adequately satisfying viewing experiences. In this paper, we present an adaptive video streaming mechanism that constructs overlay networks based on Small-World (SW) of peers. Our approach combines the key characteristics of P2P push and pull mechanisms to improve the packet delivery ratio and the overall quality of service. Furthermore, we tackle peer heterogeneity using scalable video coding (SVC) that is considered more promising for real-time applications over heterogeneous networks. Our mechanism is evaluated and compared with existing approach. The obtained results show the effectiveness of the proposed overlay organization in term of lowering the packet loss ratio and the delay jitter. This proves the application of our mechanism to live and VoD delivery.**

Keywords: P2P Network, Small-World, Overlay Organization, Push-Pull content delivery, Quality of Service (QoS).

I. INTRODUCTION

Due to the deployment complexities of IP multicast, application layer multicast has attracted more research interests and efforts. It has enabled different streaming systems to be successfully deployed and serving tens of thousands of simultaneous users having heterogeneous characteristics. Most of these systems are constituted of large number of peers forming P2P network which are organized into virtual overlay networks irrespective to their physical and geographical characteristics. P2P networks are heterogeneous and highly volatile networks. They are constructed of asymmetric network links that offer different uplink (user-to-network) and downlink (network-to-user) capacities. The difference of uplink and downlink capacities makes it difficult to retrieve in real-time, the whole media content from a single sender peer when it is the only contributor to the stream [1]. In P2P network peers join and leave the overlay networks in a distributed manner without a prior notification. This makes maintaining a smooth quality of service (QoS) an important research challenge. Our target objective is to design a P2P streaming mechanism which achieves the following goals:

- *Low Delay*: We would like to construct a P2P overlay which minimizes the delay from source to receiver peer. Real-time streaming applications are sensitive to delay. Thus an overlay with low delay is required for these applications.
- *Peer Dynamicity*: In P2P networks, peers join or leave the network at any time. The desired overlay should be able to handle peer dynamicity.
- *Scalable and Adaptive*: The mechanism should be scalable to large number of users. It should be adaptive in the sense that it continuously improves the overlay based on the existing user characteristics.
- *Maximizing Bandwidth Utilization*: Peers in the network have different uplink bandwidth. The proposed overlay should fulfill the streaming rate requirement for each peer despite bandwidth heterogeneity. It should also provide some kind of incentive mechanism (relatively lower delay) to peers providing greater contribution to overlay.

Generally, P2P video streaming systems are classified into structured (tree-based) [2] and unstructured (mesh-based) systems in terms of video content delivery. Tree-based systems implement push based video delivery mechanism in which contents are delivered following the tree path from root (source peer) to destination (receiver) peer. Although, tree based approach is simple and achieves low delay, the failure of a node can affect the streaming quality of descendants. Moreover, tree-based approaches cannot guarantee the streaming rate as it is limited by the minimum uplink bandwidth of a node in the tree. In contrast to the tree-based systems, there is no specific criterion for the organization and content delivery in mesh-based systems. Any peer having the requested content blindly pushes it to the neighbor peers following different routes. It is possible that any peer receives same part of the video content from multiple peers that results into redundancy problem. To avoid such problem, mesh-based systems implement pull-based mechanism for video delivery. In this mechanism, a peer pulls the required media content from the other peers. More recently, a number of hybrid systems based push-pull approaches have been proposed to combine both tree-based push approaches and mesh-based pull

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approaches[3][4]. In such systems, all the active peers having the video content maintain different buffer maps representing the information for the available chunks with certain peers. These buffer maps are exchanged among peers. A peer seeking for certain media content determines a schedule to pull different chunks from multiple peers.

These mechanisms facilitate the video content delivery with higher scalability and in cost effective manner. P2P systems are also considered highly volatile and dynamic in nature. To cope with the dynamicity issue and to ensure smooth QoS, they have to implement peer switching mechanism [5]. A peer participating in the delivery process and which leaves the system has to be replaced with another peer. This peer switching mechanism can add a significant overhead due to peer selection and remplacement.

We address the abovementioned issues in our proposed video streaming mechanism by combining the characteristics of push and pull content delivery and by incorporating peers organization into clustered overlays, forming a Small World (SW) [6]. Our mechanism includes (1) peers organization in different overlay network, (2) video content delivery from sender peer using push-pull mechanism, and (3) quality adaptation to serve video content to heterogeneous receiver peers in accordance to their network and terminal capabilities.

It is worth noting that the organization of peers in small world allows ensuring lower delay from source to destination peer. This organization is based on a relative priority of the sender peers contributing to the streaming.

In this mechanism different peers receive different parts of video from multiple sender peers using the push and pull mechanism as shown in Figure 1. In this figure a single peer receives video from multiple sender peers using the PUSH mechanism and the missing parts are retrieved using the PULL mechanism. In such mechanism a receiver side scheduler is implemented to orchestrate the delivery of the different parts of video from different sender peers. All the video packets received from the sender peers are combined in different buffers that are monitored regularly to identify when we need to implement pull-based mechanism to receive the missing parts of the video before their actual playback deadline.

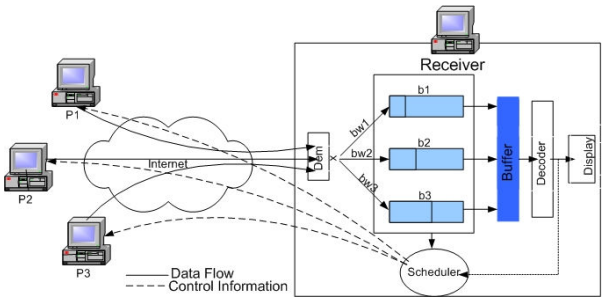

Figure 1: Architecture for Receiver Centric Video Streaming

Moreover, our proposed mechanism is based on Scalable Video Coding (SVC) that is considered more suitable for heterogeneous networks and receivers due to its simple real-time content adaptations capabilities. Furthermore, we incorporate quality adaptation over received SVC layers in accordance to the receiver's characteristics and preferences.

The rest of the paper is organized in different sections. A brief related work and motivation is presented in section 2. The proposed mechanism is described in details in sections 3 addressing major components involved in video delivery over P2P networks. Section 4 illustrates the performance evaluation and section 5 presents a brief conclusion while highlighting some of the future perspectives.

II. Related Works

P2P-based video streaming systems have attracted both research and academia and a number of solutions have been proposed to address different challenging issues. In this section, we highlight some of the known solutions that exploit the push and pull video distribution.

CoolStreaming/DONet (CS) [7] presents a framework for live media streaming based on data-driven overlay networks where each peer periodically exchanges data availability information with each other. The participating peers form a mesh network, and the peers in the data-driven overlay network are organized in a Breath-First-Search (BFS) tree. Each peer receives video content from its parent peer, after this organization. This approach organizes the participating peers into multiple trees for incorporating video delivery. This framework has shown a great improvement in the video distribution with high scalability. However, it does not incorporate the fundamental design of mesh network in the proposed solution.

PRIME [8] presents receiver-centric video streaming mechanism over P2P mesh networks. This study shows that mesh-based P2P live streaming can effectively incorporate swarming content delivery. The mesh-based networks exploit the characteristics of retrieving the missing parts of video. The main objective of this system resides in minimizing the effects of bandwidth and content bottleneck. The proposed mechanism provides high scalability and cost effective live video distribution. The underlying video encoding is based on multiple descriptions coding (MDC), however there is no real codec available for this encoding scheme that can be used for real-implementation.

"GridMedia" [9] is another well known system offering P2P-based IPTV services. It organizes the peers in unstructured overlay networks and implements a push-pull based approach to fetch the media contents from the neighbor peers. It implements a block scheduling mechanism for efficient contents sharing among the peers. The neighbor peers are selected on the random basis. The push-pull based mechanism offers the benefits of the receiver-centric approach and also reduces the overall latency. "iGridMedia" [10] is an extension of the "GridMedia" protocol that is open source solution. This protocol focuses on providing delay-guaranteed services to support real-time applications. It provides high scalability and it is considered suitable even for very large number of users, requesting for same channel.

Chainsaw [11] employed a pull based mechanism on top of an unstructured topology. Each peer is connected to a set of neighbors. Every peer creates a list of desired packets. When a peer receives a packet it sends notification to its neighbors. If notification message contains the sequence number of those packets as in desired packet list, it requests those packets from neighbor.

In contrast to the other available solutions, we proposed a mechanism to organize the peers in overlay networks forming

the small world. The participating peers are organized in two different layers on the basis of their relative priority towards offered QoS. Moreover, we incorporated push-pull content delivery mechanism that is used to receive the whole video contents that overcome the problem of simple push or pull based content delivery. Furthermore, the use of scalable video coding (SVC) makes our system more promising that is considered highly suitable for heterogeneous networks and terminals due to its real-time content adaptation characteristics.

III. Push-Pull Mechanism for Adaptive Video Streaming

Two major components are designed and implemented for our streaming system: (1) overlay organization mechanism to organize participating peers and (2) end-to-end content delivery utilizing push-pull mechanisms. The P2P system comprises these four entities: (a) Source server or Seeder, (b) Tracker, (c) super peers, and (d) ordinary peers. The source server is the seeder of the original video contents. It can be a dedicated server or an ordinary seeder peer. Tracker plays an important role in the proposed system that is responsible for assisting participating peers to communicate with each others to find their bootstrapping peers. Whenever a new peer enters the system, it contacts the tracker and provides him its IP address and its available bandwidth range. In response, the tracker provides a list of available super peers that lies in the same bandwidth range. The participating peers in P2P networks are classified as super peers or ordinary peers having distinct role in the streaming mechanism. The detailed streaming mechanism is presented in the following sub-sections.

A. Overlay Organization

In P2P networks, all the peers are organized in overlay networks that are virtual networks, constructed on the top of the physical networks. We organize the participating peers into overlay network in the form of a *small world* (SW) forming different clusters. This small world represents a class of random graph in which every peer is accessible from other peer in small number of hops [6]. The motivation of using small world is to ensure robustness and guaranteed bandwidth that can be achieved by decreasing the number of hops between source and receiver peers from application (overlay) level perspective. Thus, it decreases the end-to-end (e2e) delay that is desired for the real-time streaming applications compared to pure tree-based approach.

Let "D_k" represents the total delay to reach any peer 'k' having parent peer 'j' from a source peer 'S'. The value of "D_k" is given as:

$$D_k \quad \left(\sum_{i \quad S}^{j} D_i \right) + d_{j,k} \qquad \text{Eq. 1}$$

In Eq. 1, "$d_{j,k}$" represents the e2e delay from peer 'j' to peer 'k'. The small world network is used in order to minimize the "D_k" from source to the receiving peer. The small world overlay organization is used to minimize the delay by limiting the total number of hops between sender peers and receiver peers.

The participating peers are organized in overlay network of two layers, First layer is comprised of super peers, whereas ordinary peers are organized in second layer forming different clusters of small world. All ordinary peers in the same cluster are connected with each other forming a mesh network and also connected to a super peer. The overlay based small world peers organization is shown in Figure 2.

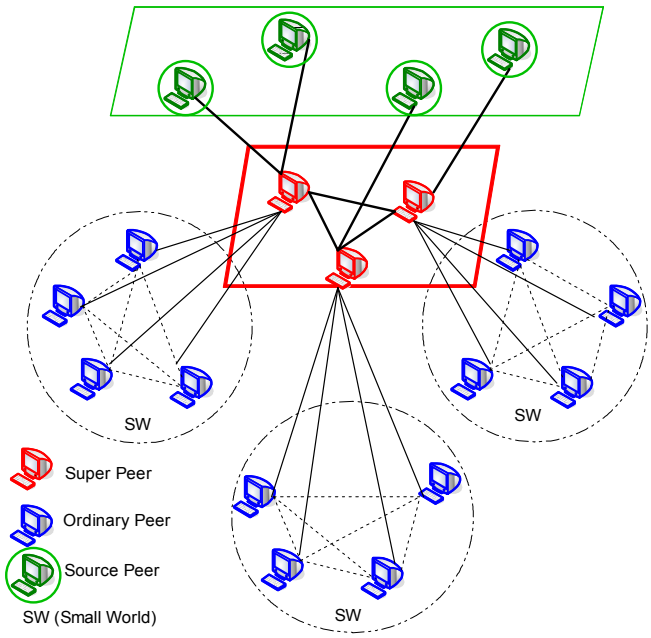

Figure 2: Small World Overlay Organization of Peers

Super peers are selected among ordinary peers due to their high uplink capabilities. The availability of multiple super peers addresses the issues of single point of failure and enhances the overall scalability of the system. An alternative super peer is selected in the case when a super peer is no more available and/or unable to contribute for the video content delivery. In the proposed architecture, all the super peers are connected to each other in a flat unstructured overlay network. Super peers are not static entities but they are dynamically selected by the tracker that keeps track of all the super peers and other participating peers. The overlay organization is carried by the super peers selection and peers joining and leaving mechanisms that are presented in what follows:

1) Mechanism for Super Peer Selection

Source Peer is responsible for distributing video contents to a fixed number of super peers that depends on the uplink bandwidth capacity of the media source and the streaming rate of the video content as presented in Eq. 2.

$$\#\,\text{SuperPeers}\,(S) \approx \frac{\text{uplink bandwidth(media source)}}{\text{rate}} \qquad \text{Eq. 2}$$

Initially, super peers are selected on the basis of their uplink bandwidth as provided to tracker while joining the network. Once streaming process starts, these super peers are periodically updated according to their contribution towards actual contents delivery.

Tracker is responsible for calculating the peers' contribution and updates the list of super peers. Tracker periodically performs the active measurement to calculate the serving strength (SS) of every peer. Serving strength is defined as the ratio of upload capacity to download capacity. This "SS" is further used to determine the contribution ratio (CR) of each peer (P_i) present in the small world.

$$\text{Contribution Ratio } P_i \text{ (CR)} \quad \frac{\text{serving strength}}{\text{distance(source}, P_i)} \qquad \text{Eq. 3}$$

The distance of a peer (P_i) from the source can be its delay time that is the time taken by packets to arrive at the peer after the source has streamed out. Eq. 3 shows that the selected super peer will exhibits the best serving capacity and more localized to media source. Thus, creating a layer of super peers can efficiently distribute the contents to overlay. The contribution ratio based selection of super peers also introduced the incentive mechanism. Peers providing greater contribution to the overlay network are selected as super peers and thus, they are able to receive contents directly from Media source. This mechanism encourages the ordinary peers to contribute more to the overlay network.

The forwarding of "CR" information to tracker may not be suitable due to its excessive overhead when there is a large number of peers present in the network. Thus, we consider the peers having "CR" value greater than a certain threshold to limit the overhead. Furthermore, we assume that no malicious peers are part of our small world because peer trust reputation is out of scope of this paper. Hence, the provided information by each peer is accurate and is used to determine the best super peer selection. Tracker regularly updates the media source about the new super peers present in the network.

2) Peer Joining Leaving

P2P networks possess dynamic characteristics where any peer may enter and/or leave the network without any prior notification. This volatility of peers is not suitable for the real-time content delivery and poses significant challenges for the maintenance of the overlay organization.

```
function Joinnetwork(Pi, BWi )
1. if (Maxsuperpeer= false)            //Initial case
2.        {Connect Pi to Msource       // Msource (Media Source)
3.          Updatesuperpeer (Pi)  //Add Pi to set of superpeers
4.          Updatesource (Pi  )  }
5.Else if { for each j∈ set_superpeer
6.{       if (Maxclustersize = false)
7.          return j
8. }
9.else { for each k ∈  set_ordinarypeer
10.       return k
11.     }
function  superpeerupdate( Pi, CSi  )  //Superpeer updation
1. for each j∈ set_superpeer
2.        { if  (CSJ  <  CSi ){
3.          Replace CSi  with CSJ
4.          Updatesuperpeer (Pi )
5.          Updatesource (Pi  ) }
6.Elseif(deadlineexpire      true) //Keepalive deadline expires
7.        {    CSJ     null
8.              superpeerupdate( Pj, CSj  )
9.         }
```

Figure 3: Tracker Algorithm

When a new peer request the tracker to joins the network, tracker in return provides a list of available super peers with in same bandwidth range. Alternatively, if there is no super peer available that can accommodate any new peer, a list of ordinary peers having similar bandwidth range is provided. In both cases, the new peer selects a super/ordinary peer from the list and sends the *join* request. Once, the new peer joins the network its parent peer (super/ordinary) updates the tracker that keeps track of number of peers joining any super peer. The algorithm for the tracker is described in Figure 3.

In P2P network when a peer leaves the network, it initiates a departure message to its parent peer that releases the outgoing bandwidth and notifies the tracker for the graceful departure of this particular peer. The other case is not trivial, when a peer suddenly leaves the network without any prior notification. This sudden departure can be encountered by periodical "*keep-alive*" message between tracker and super peers and super peers and ordinary peers. If there is no response received from any peer with in significant amount of time, it is assumed that the particular peer is no more available in the network. In return, some alternative super peer is selected to ensure the smooth content delivery.

B. End-to-End Content Delivery

The main objective of the proposed streaming mechanism is to ensure the e2e content delivery with improved QoS. In this section, we present our proposed push-pull mechanism over P2P networks.

1) Proposed Push-Pull Mechanism

The proposed content delivery mechanisms are facilitated by incorporation of push and pull modes of the contents delivery. In the first steps, video contents (different parts of SVC video layers) are pushed from source peer to receiver peer. Whereas, in the second phase, receiver peer implements pull method to acquire the missing packets of the video layers to construct the original video.

The objective of the pushing component is to quickly distribute a data block to a certain number of peers, in order to fuel the subsequent pull based exchanges. We used push-pull based mechanism to reduce the long delays of purely pull based approaches, because of the striking latency accumulated hop by hop. Push-Pull mechanism greatly decreases the latency and inherits simplicity and robustness of traditional pull method. Thus, the proposed push-pull mechanism can obtain the same delivery ratio with much smaller absolute delay than the simple pull method.

In order to increase the packet delivery ratio, each super-peer, proactively push data packets to connected ordinary peers. We implement a buffer map for the video contents available at different peers. The buffer map provides information for the respective sequence number and the playback deadline for this video packet. Some of the video packets are lost during transmission due to the unreliability of the network links and/or network congestion over particular links. An overlay peer can easily detect missing packets by using gaps in the packet sequence numbers. This information is used to pull the missing packets from other members present in the cluster. The algorithm for pull mechanism is similar to the heuristic used in CoolStreaming/DONet and BitTorrent [12]. If cluster members are unable to provide those packets, missing packets are requested from super peer. The flat hierarchical structure of super peer layer, allows fetching the contents from other super peers.

In our proposed mechanism, we focus to retrieve the missing parts of the video from alternative peers instead of implementing peer/stream switching mechanism [12] that adds significant overhead. However, if the missing video packets are not available with ordinary peers then peer switching mechanism is inevitable. In peer switching mechanism, an alternative source peer is selected and receiver-side scheduler assign to retrieve the missing part of video from this peer.

In P2P networks, peers are interconnected through asymmetric networks link. In this scenario, a single sender peer is not capable to deliver high quality video contents. In our mechanism, a receiver side scheduler plays an important role in video content sharing mechanism. Generally, there is large number of source peers available in the network for popular video contents. However, in real-time video sharing it is not acceptable to communicate with a large number of source peers simultaneously. The e2e communication among each sender and receiver peers add significant overhead that degrade the QoS for real-time streaming. Thus, receiver peer orchestrates the whole streaming mechanism and selects a limited number of source peers. The scheduler determines that which part of the requested video will be receive from which source peer. The selection and assignment of video parts is based on the relative priority of each source peer towards offered QoS.

2) *Quality Adaptation*

Quality adaptation becomes important when a receiver peer select multiple sender peers to receive any video. This mechanism is essential in delivering the video contents with respect to receiver's network, terminal capabilities and other preferences over heterogeneous networks where participants possess distinct characteristics. We focused to use H.264/SVC [13] for encoding the original video contents that are used to produce highly compressed bit streams to generate a wide variety of bit rates. In such video encoding schema, original video stream is truncated into many different video layers. The "base layer" provides a significant proportion of the video quality whereas the "enhancement layers" are used to enhance the video quality in different dimensions. "Base layer" is considered as the most important layer because all the "enhancement layers" are only decodable with reference to lower layers and "Base layer".

The packet ordering based quality adaptation not only ensures the base video quality for streaming session but also adds resilience for the lower video layers. The packet's ordering highly depends on the receiver preferences towards the perceived quality. SVC based video coding offers the receiver to select the video either with high SNR quality, temporal resolutions for varying frame rates, or spatial resolution for the different resolutions.

In the proposed mechanism, receiver peers receive different parts of the video from sender peers through the "super peers" while employing the "Zigzag pattern" for content delivery [12][14].

IV. PERFORMANCE EVALUATION

This section describes the performance evaluations of the proposed adaptive video streaming mechanism for different QoS parameters using NS-2 simulations [15].

A. *Simulation Setup*

We performed intensive simulations to study the performance of our proposed mechanism in order to quantify the overall QoS parameters against CoolStreaming (CS) mechanism that implements push-pull based content delivery mechanism on an organized overlay structure.

Performance Metrics: The performance evaluation is carried for different QoS metrics that include: packet delivery ratio, delivery Latency, hop count and Jitter. These parameters have significant role in determining the overall QoS for the real-time streaming applications.

Video Coding: We used H.264/SVC as encoding scheme. We truncate the original SVC video in different layers (base layer and enhancement layers) and distribute them among different super peers. However, our main focus resides to evaluate the above stated QoS parameters.

Network Topology: We used the BRITE universal topology generator [16] in the top-down hierarchical mode to map the physical network. The network topology consists of autonomous system (AS) and fixed number of routers. All AS are assumed to be in the Transit-Stub manner. Peers are attached to the routers randomly. The delay on the access links are randomly selected between 5 to 10 ms. Moreover, each super peer is further connected to 4 ordinary peers within each cluster. The incoming bandwidth of super and ordinary peers varies between 512 kbps to 5 Mbps and is uniformly distributed throughout the network. We deployed a single media source and the uplink bandwidth of media source is also randomly selected from above mentioned range. Peers join the network at random intervals. We also introduced sudden peer departure at random intervals.

B. *Results and Discussion*

Figure 4 shows the average delivery ratio for our proposed solution in comparison to "CS". Delivery ratio is defined as the number of packets delivered before deadline over total number of packets encoded. Packets are proactively pushed to ordinary peers in the small world. A gap in sequence number identifies the missing packets. These missing packets are requested from the other members of small world. If a packet is pulled successfully within its playback deadline it is consumed otherwise dropped. Figure 4 depicts that both "CS" and proposed mechanism perform better with increasing swarm size, however, "CS" has lower packet delivery ratio due to random content delivery as compared to our proposed small world where content flow in an organized way. The reason is that swarming based protocols are not affected with increasing number of peers. The obtained results indicate that the performance of small world based push-pull protocol remains almost same with increasing number of peers where more than 85% packets are received before playback deadline. Thus, the improved packet delivery ratio ensures the smooth content delivery.

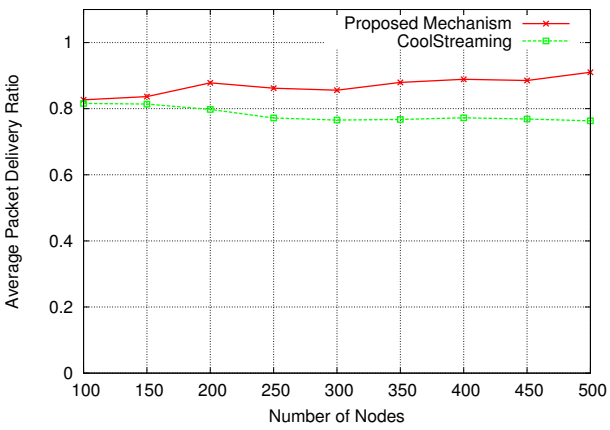

Figure 3: Packet Delivery Ratio

Figure 5 shows the delivery latency experienced by data packets at different peers. We measure the average time for first packet arrival, for both mechanisms. We noticed that both models suffer from increased average time of first packet arrival, however, they stay relatively constant with increasing number of peers. Due to the existence of super peers and push-pull delivery, packets have higher chances to be delivered to the connected clients in a smaller period of time. The other reason is the systematic flow of content among different small worlds with near optimal overlay hops.

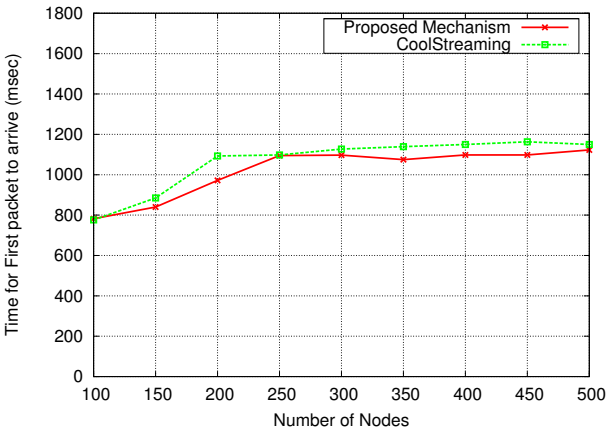

Figure 4: Average Packet Latency vs. # of Peer

Moreover, we evaluated the jitter rate for the both mechanisms and the results are presented in Figure 6. The unavailability of a packet at its playback time causes a jitter.

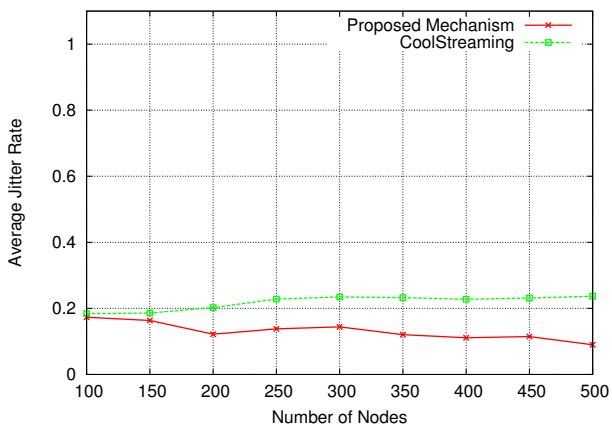

Figure 5: Average Jitter Rate vs. # of Peers

Our proposed mechanism has comparatively lower jitter rate as compared to CS. Sometimes an intermediate piece which can not be fetched may increase the jitter rate. In our proposed mechanism chances of missing packets are relatively low due to organized content flow. If a packet is acquired by a cluster member, it implies that there are at least one or more sources for the contents. This flow of contents saves times as compared to CS.

Figure 7 shows the comparison of average delivery ratio with varying streaming rates. It is observed that as streaming rate increases, the delivery ratio for proposed mechanism remains relatively high. Even with the streaming rate greater than 500Kbps, delivery ratio is greater than 80%. This shows that network capacity of proposed mechanism is sufficient to support higher streaming rate.

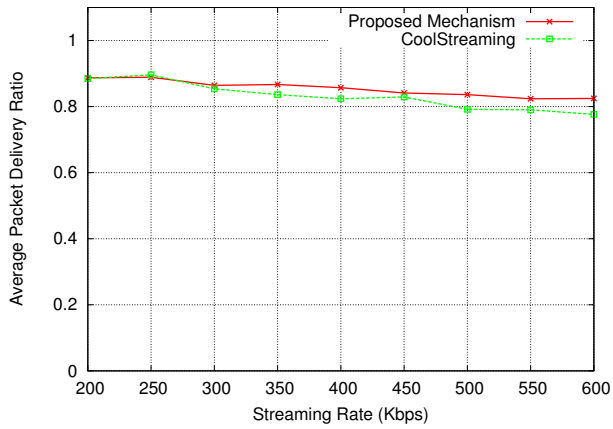

Figure 6: Average Delivery Ratio vs. Streaming Rate

Figure 8 shows the average hop count of the proposed mechanism in comparison with CS. Hop count is referred as the number of intermediate peers involved on the overlay path from source to receiving peer. It is important to note that small overlay path doesnot necessarily guarantee small delay, however we want to emphasize the organization of overlay using proposed mechanism. It is observed that proposed mechanism have less number of hop counts due to organization of peers in small world.

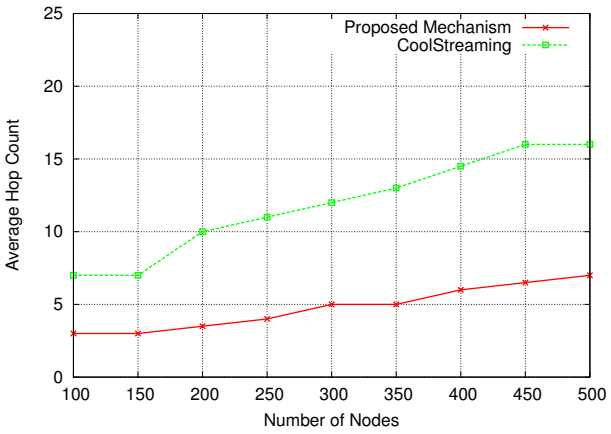

Figure 7: Average Hop Counts vs # of peers

V. CONCLUSION FUTURE PERSPECTIVES

We presented an adaptive video streaming mechanism by organizing the participating peers in clustered overlay networks in the form of small world. The overlay organization is influenced by the "contribution ratio" of the peers towards content delivery. The overlay is organized into two independent layers for super peers and ordinary peers. The actual content delivery is facilitated by a combined push-pull mechanism. This mechanism allows receiving the full video content by explicitly fetching the missing parts of video. Our proposed mechanism resulted in improved packet delivery and reduced latency to guarantee overall QoS for the video content. The proposed mechanism is evaluated by network simulations. The obtained results show remarkable improvements in the received video quality. Furthermore, the organization of peers into cluster provides better content delivery and content distribution.

For the future perspective, we aim to extend the proposed overlay organization and push-pull mechanism to a large P2P network having multiple sender peers arriving at different intervals. Furthermore we want to investigate the effect of churn on our proposed mechanism. We aim to perform real-time evaluation for the more personalized VoD and IPTV service.

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