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SWOR: an Architecture for P2P Scalable Video Streaming using <u>S</u>mall <u>W</u>orld <u>O</u>ve<u>r</u>lay

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Abstract— **In this paper we propose SWOR, an architecture to deliver Scalable Video Coding (SVC) contents over P2P network. SWOR architecture is based on twofold mechanisms: (1) organization of peers in Small-World (SW) overlay networks, (2) delivering SVC content using push-pull mechanism. SWOR is evaluated and compared with CoolStreaming/DONet (CS) on QoS metrics using NS-2 simulator. Performance evaluation demonstrates that SWOR outperforms CS and provides a significant improvement in the received video quality in terms of lowering the packet loss and transmission delay.**

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

I. INTRODUCTION

Over the past few years, P2P networks have emerged as a promising approach for distribution of multimedia contents over a large scale network. Recently, we have been witnessing the emergence of novel P2P applications such as P2P audio and video streaming. P2P streaming focuses on the efficient delivery of audio and video content under strict timing requirement. For real-time video streaming applications over P2P networks, a single sender peer cannot provide sufficient bandwidth to ensure smooth video delivery. This makes maintaining a smooth quality of service (QoS) an important research challenge. Our target objective is to design a P2P streaming architecture which achieves the following goals:

- *Low Delay*: Real-time streaming applications are sensitive to delay. Thus, an overlay with low delay is required for these applications. We intend to construct a P2P overlay which minimizes the delay from source to receiver peer.
- *Peer Dynamics*: In P2P networks, peers join or leave the network without prior notification. The desired overlay should be able to handle peer dynamicity.
- *Scalable and Adaptive*: The architecture should be scalable for large number of users. It should be adaptive in the sense that it continuously improves the overlay based on the existing user characteristics.
- *Quality Adaptation*: Assigning different parts of the video contents to specific peer in order to ensure stable QoS.

We address the above mentioned issues in our proposed video streaming architecture (SWOR) by combining the characteristics of push and pull content delivery and by incorporating peers organization into clustered overlays forming a Small World (SW) [1]. In this architecture 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 SWOR 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.

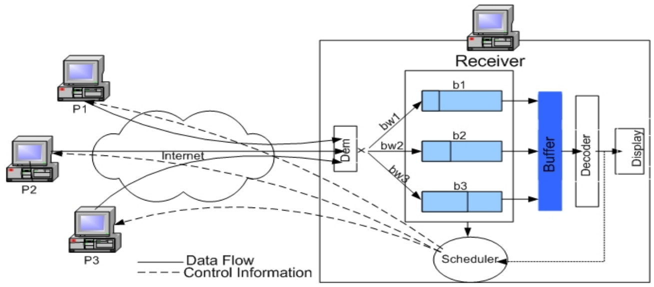

Figure 1: Architecture for Receiver Centric Video Streaming

The proposed architecture is based on Scalable Video Coding (SVC) that is considered more suitable for heterogeneous networks and receivers due to its real-time content adaptations capabilities. In SVC encoding scheme, each video stream is encoded into multiple video quality tiers.

The rest of the paper is organized in different sections. A brief related work and motivation is presented in section 2. The proposed architecture 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

There have been tremendous efforts in the design and experimentation of video streaming systems in the past two decades, yet no single system has delivered the expected scalability and QoS [2]. In this section, we highlight some of the known solutions that exploit the push and pull video distribution.

CoolStreaming/DONet (CS) [3] presents a framework for live media streaming based on data-driven overlay networks where peers periodically exchange data availability information with each other and retrieves the unavailable data. This framework has shown great improvement in the video distribution with

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high scalability, however it has two main drawbacks: (1) long initial startup delay due to random peer selection process, and (2) higher failure rate in joining a program during flash crowd. GridMedia [4] is a 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. The iGridMedia [5] focuses on providing delay-guaranteed services to support real-time applications for large number of users. There have been several recent works, which focused on effective content searching using the properties of small world.

There are several fundamental questions that are unclear such as how an overlay evolves under a random peer selection scheme, in what sense is the system scalable and what are the limitations and trade-offs. The existing works didn't provide a comprehensive study on these crucial issues. In this paper, we proposed an architecture to organize the peers in overlay networks forming the small world. We attempt to provide an efficient P2P media streaming model based on chunk driven philosophy and a unique peering scheme to counter the shortcomings mentioned earlier.

III. SCALABLE VIDEO STREAMING ARCHITECTURE

Two major components are designed and implemented for SWOR: (1) overlay organization mechanism to organize participating peers and (2) end-to-end content delivery, utilizing push-pull mechanisms. The proposed P2P architecture comprises of four entities: (a) Source peers, (b) Tracker, (c) Super peers, and (d) Ordinary peers. The source peers are the seeders of the original video contents. Tracker plays an important role in the proposed architecture that is responsible for assisting participating peers to communicate with each others to find their bootstrapping peers. When a new peer enters the network, it provides its unique identity and bandwidth range [IP, BW] to tracker. The detailed streaming architecture is presented in the following sub-sections.

A. *Overlay Organization*

We organize the participating peers into overlay network in the form of a *small world* (SW) forming different clusters. The small world represents a class of random graph in which every peer is accessible from other peer in small number of hops [1]. Furthermore, in small world every node has an intense local clustering and it shares an edge with some far located nodes in the network. This ensures that once a packet is in the cluster, it can be easily obtained by other members of same cluster. 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. To mathematically define the shortest hop property of small world, let $G = (N, E)$ denote a connected graph representing a small world network. Let $D(i, j)$ represents the length (in hops) of the shortest path between two nodes i and $j \in V$.

Definition 1: The average shortest hop count of a graph G, denoted as $F(G)$, is equal to

$$F(G) = \frac{1}{\binom{N}{2}} \sum_{i,\, j \in V} D(i, j) \qquad \text{Eq.1}$$

$F(G)$ is the ratio of the sum of all shortest paths between any two nodes in G and all possible pair wise connections of the connected graph.

The participating peers in SWOR 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 (intense clustering) and also connected to a super peer. Super peers are connected to each other in a flat hierarchical structure as shown in Figure 2. This structure is similar to small world network, where nodes are connected to each other (ordinary peer) and also have some links elsewhere in the network (super peer).

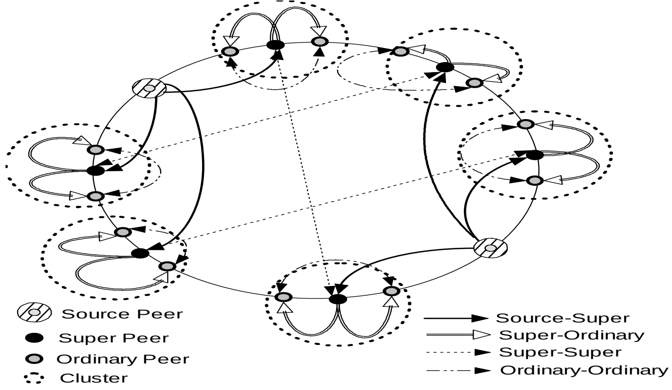

Figure 2: SWOR Overlay Organization

Super peers are selected among ordinary peers on the basis of their serving strength towards the overlay network. The availability of multiple super peers addresses the issues of single point of failure. 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. Super peers are not static entities but they are dynamically selected and updated by the tracker. The overlay organization is carried by the super peers selection and peers joining and leaving mechanisms that are presented in following subsections:

1) *Mechanism for Super Peer Selection*

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

$$\#\,\text{SuperPeers (S)} \approx \frac{\text{Bandwidth}_{\text{out}}\,\text{(source peer)}}{\text{Streaming rate}} \qquad \text{Eq. 2}$$

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 content delivery. Eq. 2 is also used to calculate the maximum number of ordinary peers in a cluster.

Tracker is responsible for calculating the peer's 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.

$$\text{Contribution Ratio } P_i \text{ (CR)} = \frac{\text{Serving strength}}{\text{Distance(source}, P_i)} \qquad \text{Eq. 3}$$

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 exhibit the best serving capacity and more localized to source peer. 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 source peers. This mechanism encourages, ordinary peers to contribute more to the overlay network.

The "CR" estimation is carried out by every peer and obtained information is sent to tracker periodically. This "CR" estimation may not be feasible due to its excessive overhead when there is large number of peers present in the network because every peer performs such calculations. Thus, we consider the ordinary peers having "CR" value greater than a certain threshold to limit the overhead. Tracker regularly updates the source peers about new super peers present in the network. Each source peer also provides its "CR" estimates to tracker. All the source peers are organized on the basis of their respective offered QoS. The best one is assigned high quality layer "Base Tier" and the enhancements tiers are assigned to the source peers in descending orders of "CR" estimates. Furthermore, we assume that no malicious peer is 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.

2) *Peer Joining & Leaving*

When a new peer requests the tracker to join 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. The receiving super peer can accept the request or reject it (depending on cluster size). In case of rejection or no reply, requesting peer timeout after a short time interval and continues its search. 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. This information is used for the future reference because each super peer can support only a limited number of ordinary peers.

Ideally 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. In SWOR, sudden departure is encountered by periodical "*keep-alive*" message between tracker and super peers and super peers and ordinary peers. If there is no response received from a 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 architecture is to ensure the End-to-End content delivery with improved QoS. In this sub-section, we present our proposed push-pull mechanism over P2P networks.

1) *Proposed Push-Pull Mechanism*

The proposed architecture is facilitated by incorporation of push and pull modes of the content delivery. In the first steps, video contents are pushed from source peers to receiver peers after passing through super peers. 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 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 a video packet. This information is used to pull the missing packets from other members present in the cluster. These buffer maps are exchanged periodically among ordinary peers within cluster. Buffer maps are also exchanged among super peer for content sharing. 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 clusters.

In our architecture, a receiver side scheduler plays an important role in video content sharing mechanism. Generally, there are a 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 scheduler determines which part of the requested video will be pulled from which peer in the cluster.

2) *Quality Adaptation*

Quality adaptation becomes important when a receiver peer select multiple sender peers to receive any video. We focused to use H.264/SVC [7] 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". Initially the source peer distributes the "Base Layer" among all super peers. The enhancement layers are exchanged among the clusters using the flat hierarchical structure of the super peers. 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 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.

IV. PERFORMANCE EVALUATION

This section describes the performance evaluations of SWOR for different QoS parameters using NS-2 simulations.

A. Simulation Setup

We performed intensive simulations to study the performance of SWOR 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, jitter and video throughput. 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 source peers. We perform simulations to receive the video quality of CIF/CGSO with 15 fps. We generated four different quality tiers using MPEG-4 trace files [9]. These quality tiers are generated by fractions of DCT (Discrete Cosine Transform) matrix. Base Tier (T0,S0,B0) offers 40% throughput of original video, enhancement tier 1 (T1,S0,B0) offers 30% throughput of original video, enhancement tier 2 (T0,S1,B0) offers 20% throughput of original file and enhancement tier 3 (T1,S1,B0) offers 10% throughput of the original video file.

Network Topology: We used the BRITE universal topology generator [10] 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. Each topology consists of 8 autonomous systems each of which has 625 routers. This gives us about 20000 links in the topology. The delay on inter-transit domains and intra-transit domains are assumed to be 90 ms and 40 ms respectively, while delay on stub-transit is assumed to be 30 ms and intra-stub transit links are randomly chosen between 5ms and 30ms. The incoming bandwidth of super and ordinary peers varies between 512 kbps to 5 Mbps and is uniformly distributed throughout the network. We deployed multiple source peers providing different layers of original video. The uplink bandwidth of source peers are also randomly selected from above mentioned range. The maximum numbers of super peer connected to source peers are calculated using equation 2, described earlier. Peers join the network at random intervals. We also introduced sudden peer departure at random intervals. The presented results are the average results of the multiple runs of these simulations.

B. Results and Discussion

Figure 3 shows the average delivery ratio for SWOR 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. 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 3 depicts that both “CS” and SWOR 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 architecture where content flow in an organized way. Due to existence of super peers and push-pull delivery in SWOR, packets have higher chances to be delivered to the connected clients in a smaller period of time. Packet delivery ratio for SWOR improves with increasing number of nodes. The reason is that increase number of clusters causes more contents to flow from one cluster to other. The obtained results indicate that the performance of SWOR remains almost same with increasing number of peers where more than 85% packets are received before playback deadline. Figure 4 shows the average overlay hops from source to destination peer. The organization of peers into small world decreases the average hop counts for SWOR.

Moreover, we evaluated the jitter rate and the results are presented in Figure 5. The unavailability of a packet at its playback time causes a jitter. SWOR has comparatively lower jitter rate as compared to CS. Sometimes an intermediate piece (data packet) which can not be fetched may increase the jitter rate. In our proposed architecture 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.

The throughput of different video tiers at the receiver peer is obtained and plotted for both SWOR and CS. We noticed that SWOR improved the received throughput as compared to CS. Figure 6(a), 6(b), 6(c) and 6(d) presents the comparison of original base tiers, enh. tier 1, enh. tier 2, and enh. tier 3 respectively. By analyzing the obtained results, we can notice that our proposed architecture provides smooth video delivery with higher quality and lower loss as compared to CS.

We combined the different received SVC layers at receiver peers to construct the original video that is further used to evaluate QoS at application level through the peak signal to noise ratio (PSNR) and structural similarity (SSIM) [11] index measurements. PSNR is commonly used for measuring picture quality degradation for the received image quality compared to the original image, whereas SSIM index measures the structural similarity between the original and the received image. The comparison results for PSNR and SSIM of the video generated in both architectures with reference to the original video are shown in Figure 7 and Figure 8 respectively. PSNR and SSIM measurements show a remarkable improvement in the received video quality in case of SWOR.

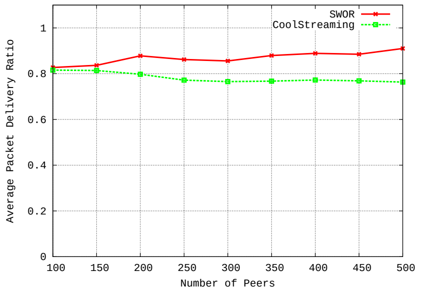

Figure 3: Packet Delivery Ratio

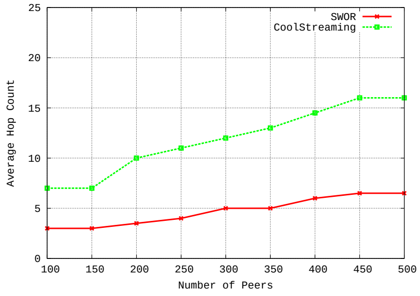

Figure 4: Average Hop Counts

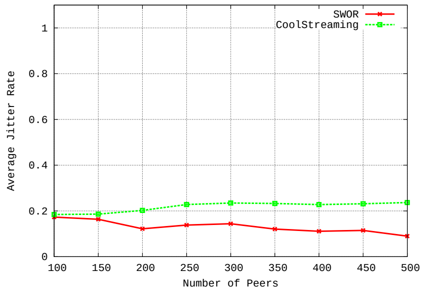

Figure 5: Average Jitter Rate

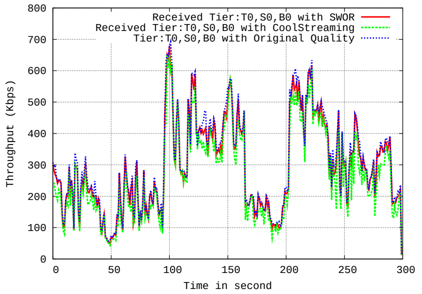

Figure 6(a): Received Base Tier

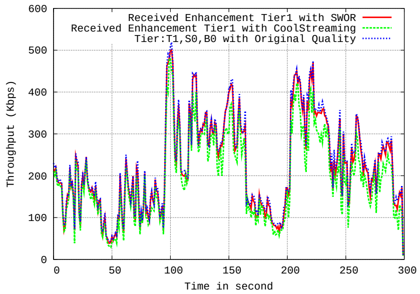

Figure 6(b): Received Enh. Tier1

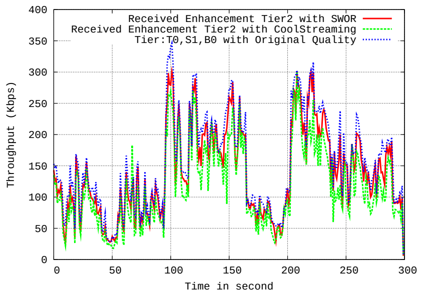

Figure 6(c): Received Enh. Tier2

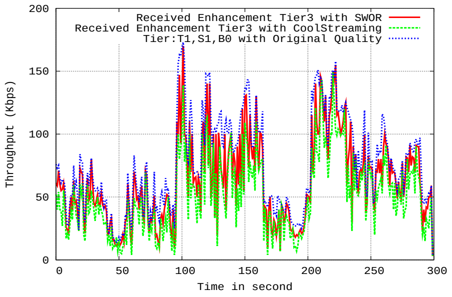

Figure 6(d): Received Enh.Tier3

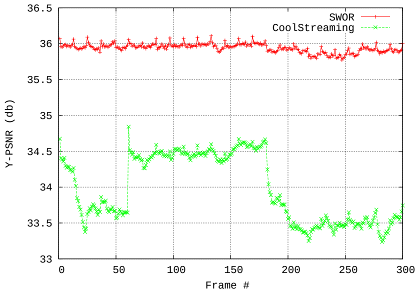

Figure 7: PSNR Measurements

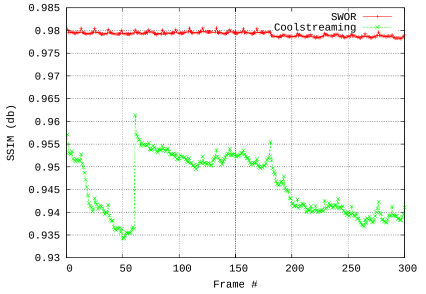

Figure 8: SSIM Estimates

V. CONCLUSION & FUTURE PERSPECTIVES

In this paper, we introduced a new architecture for scalable P2P media streaming namely SWOR. It utilizes small world peering organization on overlay to deal with the existing problems in chunk based streaming systems. SWOR evaluation against CS resulted in improved packet delivery and better video quality. Results also showed a significant reduction of average number of overlay hops which leads to lowering the transmission delay. The proposed SWOR architecture incorporates SVC to ensure smooth video quality delivery with guaranteed adapted QoS. Finally, we believe that our results are promising and could provide research insight towards development of newer and efficient peering strategies in P2P media streaming systems.

For the future perspective, we aim to perform real test-bed evaluation for the more personalized VoD and IPTV services delivery over P2P network.

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