A Distinctive Analysis of New Hybrid Overlay Approach with Classical Overlay Approaches for P2P Live Streaming

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Abstract – Peer to peer networks has had been an indispensable part of data as well as video transmission from the last few years over the internet. Live video streaming has a significant role in video transmission. The two major factors which affect the performance of live video streaming in peer to peer networks are overlay construction and data scheduling. Tree Overlay and mesh overlay are the basic overlay approaches for peer to peer networks, but both the approaches do not provide an optimum solution to live video streaming. So, a combination of both the methods "Hybrid overlay" is being applied which tries to provide an efficient overlay approach. In this paper, we have implemented the New Hybrid Overlay approach which combines the different parameters which are critical in overlay construction like upload bandwidth, the stability of peers, etc. A comparative analysis of the various overlay approaches is done with the New Hybrid Overlay Approach and Denacast Approach. The simulation results have been presented to discuss the viability of this new proposed Hybrid Approach and the other different overlay approaches in respect of end to end delay, Playback delay, start-up delay, and frame loss.

Keywords: Live video streaming, Peer to Peer Network, Content Delivery Network, Resource utilization, ISP traffic.

1. Introduction

It has been estimated that media transmission will witness an increase in congestion of up to 90% on the internet till the end of 2019, according to Cisco [1]. There has been a massive boost in the demand for video by internet users. The variety of application areas where video over the internet can be used is communication, security, education, entertainment, etc. [2]. The two different categories in which transmission of video over the internet can be classified into are Video on demand (VoD) and live video streaming. Video on demand is more users friendly in comparison to live video streaming. In the video on demand, the consumer has the benefit of having access to the video in any instance, there no restriction related to any real-time constraints while; there are restrictions related to real-time constraints in live video streaming. In live video streaming the consumer can enjoy the video only at a particular broadcast time [3]. If a user misses that broadcast time, then there is no other option and the consumer has to use the video on demand mechanism only to enjoy the video. As after the particular broadcast time video is no more available on the live video streaming server. As the request for video streaming increases, the complexity and cost at the server side also increase in the traditional client-server architecture. Also, the server is the only source to fulfil the demand of the users. So to maintain the demand-supply relationship, there is a requirement for another approach which is less cost effective as compared to the client-server architecture [4].

Peer to peer (P2P) network is the most competent method for managing this major concern of increasing complexity and server side cost. P2P is a distributed network, and the task of uploading the content in the network is a jointly handled by both server and the peers. The peer upload bandwidth is also used for uploading the content in the network, so utilization of resources is more in the P2P network as compared to the traditional client-server architecture. The proficient bandwidth use of peers in P2P network makes them scalable. Thus, the requirement for a new user can just be satisfied without having any additional weight on the server. Live video streaming in P2P network is implemented in CoolStreaming, and it is considered as a landmark in video streaming. The implementation issues in DoNet/CoolStreaming are discussed by X. Zhang et al. [5]. For overlay construction in CoolStreaming; gossiping protocol is used and for content distribution, swarm based approach is used. Multiple improvements over CoolStreaming and several important factors like 'churn' have also been discussed in detail in [6].

The fundamental design issues related to CoolStreaming and its execution have been described by SusuXie et al. [7]. Providing a non-optimal real time working environment is the prime concern of this work. Randomized peer selection approach is used for finding the neighbour peers using the real traces. For solving the problem of dynamicity the heterogeneity buffer management techniques are used. Other

challenging issues regarding the P2P networks are discussed by B.L.B.Li et al. [8]. The upload capacity, heterogeneity, and firewall also affect the performance of the network. Cross-ISP traffic and NAT (Network Address Translation) issues are discussed by B.Li et al. [9]. There are various ISP-friendly approaches which can provide a solution to the problem of cross-ISP traffic [10][11].

Overlay construction, Flash crowd, and Scheduling schemes are some of the key research areas in P2P networks. In this paper, Overlay construction and different issues related to overlay construction which has an impact on the performance of P2P networks will be discussed. A comparative analysis of the different overlay construction techniques, with associated metrics and implementation issues, have been examined in detail.

2. Overlay

According to the types of overlays that are studied, the overlay can conventionally be classified into two categories namely Tree overlay and Mesh overlay.

1.1 Tree Overlay

Data transfer between the peers in P2P network is the prime responsibility of network layer. Unicast, broadcast, and multicast are the core and practical approaches using in data transfer between the peers. IP multicast is a very modern approach which is used in data transfer when the numbers of peers are more than one. On the other hand, this approach has some issues like Network Address Translation (NAT), congestion, flow control, error control, and scalability that influence and have a significant impact on the performance of the network [12]. End system multicast or Application Layer Multicast is another approach which can provide a solution to the problems in IP multicast. In IP layer multicast intermediate device has the capability to forward the packets and end device only works as a receiver. But in the application layer, multicast forwarding is also a responsibility of end device, and they can forward the data to another device. This makes the overlay network more scalable, easy to handle and the system becomes more adaptable to system failure.

In tree or multi-tree overlay data is transferred from source to leaf peers. So generally push based scheduling scheme is applicable for tree overlay. Every child receives the data from its parent only, and the parent peer has full responsibility of transferring the data to all its neighbours (immediate or indirect neighbours). If a parent is more dynamic in nature and leaves the network frequently then, it becomes a tedious task for the child to find another parent again and again. And if the dynamic parent is above in the hierarchy then it affects the performance of the entire network. Complexity and maintenance cost of the network increases as the number of dynamic peers in the network increase. So, the stability of the peers in the network affects the performance of the network. Some of the examples of Tree-based overlay are ESM and NICE [2].

1.2 Mesh Overlay

Tree overlay doesn't have optimum resource utilization so; there is a requirement for a different overlay. The solution to all the issues which are discussed in tree overlay could be provided by using the mesh overlay. The peers available in the mesh overlay are connected to all other peers in the overlay. Bandwidth utilization in mesh overlay is more as compared to tree overlay. In the tree overlay, the upload bandwidth of the leaf node is not utilized, however in mesh overlay each peer is connected to other peers in the network, so there is no concept of a leaf node. And each peer can upload using their upload bandwidth so overall resource utilization of P2P network increases [13]. Peers are connected to more than one peer so; peer dynamicity is also not a big issue in mesh overlay. If a peer leaves the network, then there is no phase for finding the parents again, because the peer is already connected to other peers so it can receive the required data from other connected peers. Some of the examples of mesh overlay are Cool-Streaming, Bullet, Any-See and Chainsaw [14]. But mesh-based overlay suffer from large startup delay because the structure is not pre-defined and when a new peer comes in the network it has to establish communication with all the other peers in the network. While there is no such scenario in tree overlay as the structure is fixed between the peers and peers, maintain a parent-child relationship.

The solution to the QoS problems of live video streaming in peer to peer is provided using a novel approach TURINstream [15]. In this approach, peers form a cluster according to their upload bandwidth, so the peers that are having the same range upload bandwidth come under the same cluster. Control and media packets are different, so different overlay has to be created for different packets in TURINstream. The simulation of the approach is implemented on Planet-Lab, and the prototype of the approach has been developed. For testing purpose, a prototype of the approach was developed taking parameters like the flash crowd, dynamic nature of peer and limited upload bandwidth into consideration.

1.3 Hybrid Overlay

Unstructured overlay construction in P2P network can be classified into Tree overlay and mesh overlay. However, both approaches are not ideal and have their pros and cons. Transmission delay in tree overlay is less compared to mesh overlay while resource utilization in tree overlay is not as good as mesh overlay. Start-up delay in mesh overlay is higher compared to tree overlay due to the parent-child relationship between the peers. If peers are dynamic in nature, then it is easy to handle them in mesh overlay as compared to handling them in tree overlay. So, both the overlay approaches are not perfect, and some authors have tried to provide a solution of deal with limitations of both approaches by using a combination of tree and mesh overlay and providing the hybrid overlay. Q. Huang et al. [16] have defined this combination of both overlays; one overlay is

used for data mesh while the other is used for control tree. For maintaining the data between the peers, the control tree is used, and control packets are sent through the tree overlay while; for actual data transfer data mesh overlay is used. Geographical location of the peer is used for creating the control tree overlay and layered peer mechanism is used for creating the data mesh overlay. Periodically, the efficiency of peers is checked and if the peer is not efficient then that peer is removed from the overlay.

Another approach ToMo, for the hybrid overlay is defined by S. Awiphan et al. [2]. This approach implements the tree overlay over mesh overlay means; mesh overlay is created first, and if there are many peers, then a tree overlay is formed. The balance between the tree and mesh overlay is created by using the method that mesh overlay height is one more as compared to the tree overlay height. The source peer maintains the height of the tree and mesh overlay. If the numbers of peers are less, then only mesh overlay is there, and there is no need for a tree overlay. However, the complexity at the source node is very high because every peer directly sends the control packets to the source peer.

Huey-Ing Liu et al. also considered the different parameters which play a crucial role in Overlay Creation. Internet Service Provider (ISP) is used for creating the subnet in the network, and further these subnets are distributed into clusters. For creating the cluster bandwidth of the peer is used. Peers with same bandwidth range are put together, and they form a cluster. Mesh overlay is created between the peers of the same cluster. Through mesh overlay intra-cluster data passing takes place and for an inter-cluster tree, the overlay is formed between the different clusters. On behalf of all the peers in the cluster, a cluster head makes the decision. If clusters are on different layers, then communication between them is prohibited. Inter-cluster communication takes place through tree overlay, so the resource utilization of peers is not appropriate [17]. Another approach which combines the P2P network and Content Distributed Network(CDN) is discussed by Thinh Nguyen Kim et al. [18]. The approach that is group-based CDN-P2P hybrid architecture (GCP2P) tries to leverage the properties of both the approaches together. GCP2P provides scalability, reliability, less control overhead, and interrupt latency. A super-peer is created according to the physical distance from the server. After selection of super peers sub-overlay are created and for the sub-overlay location of the peer is used. The simulation results prove that regarding start-up delay, the performance of GCP2P approach is better as compared to the P2P and CDN approaches individually.

Bandwidth utilization is the prime consideration in P2P network overlay construction. Another approach which works on the same concept is discussed by C. Hammami et al. [13]. Hybrid Live P2P Streaming Protocol (HLPSP) is a novel approach which combines both tree and mesh overlay. For creating the tree upload bandwidth of peers is used. If peers have higher upload bandwidth, then it will be above in the hierarchy. The source works as a root node, and it is at level 0. Comparison of the approach is made with Denacast approach, and the approach provides better data flexibility, less control overhead, and less start-up delay. But the problem with the approach is that the author has just considered the upload bandwidth as a prime factor but hasn't taken other factors like delay, geographical location and dynamic nature of peer, etc. into consideration which also affects the overlay construction.

To solve the issues of overlay construction and for providing a new overlay, a technique using different crucial factors which influence the performance of P2P network in live video streaming we offer a new overlay construction scheme [19]. This new hybrid overlay approach is a combination of both tree and mesh overlay. In this approach, the different parameters like upload bandwidth, geographical location, content id, and stability of peers are considered to create an overlay. Various levels are designed for tree overlay and for creating the levels remaining upload bandwidth of a peer are used. Stability of each peer is calculated using the threshold value th2. Stable peers are used for creating the tree overlay with the combination of remaining upload bandwidth. After creating a stable tree overlay, the mesh overlay is created using the remaining stable peers and the mesh is not entirely mesh.

In this paper, we simulate the new hybrid overlay with other basic and hybrid approaches and provide the results that support our approach. Different parameters like playback delay, start-up delay, frame loss ratio, the end to end delay and packet drop due to an unreachable destination are used to verify the result.

3. System Model

The system model which we used for live video streaming in P2P network is discussed in this section. There is a tracer node *T*, and *T* maintains the collection of data available with each peer. The video, connectivity, neighbour relation, stable peers and upload/download bandwidth all these details of each peer are maintained by the tracer peer. There are n servers and among these n servers, the tracer gives first preference to that server which is free from the server set $\{S_0, S_1, S_2 \ldots S_n\}$. The network is heterogeneous, so the bandwidth of each peer is not same however it is limited so that every peer can connect up to a limited number of peers. No admission control policy is applicable on P2P network so there may be any number of peers that can send the request at any time. $\boldsymbol{N_{bri}}$ is the upmost number of neighbours for node *i*. But the number of neighbours of peers may be different, and it may be in the range of *{0, N}* where N is the maximum number of peers in the network. When a new peer *p* enters the network, it sends the request to the tracer. Tracer creates a list of possible parents $\boldsymbol{Np \subseteq N}$ peers who can fulfill the demand of requesting peer. $\boldsymbol{Np}$ is the set of best available peers which have the same video as is requested by requesting peer, and *N* is the total number of peers in the network. A Buffer Map ($\boldsymbol{B_{fi}}$) is used for the purpose of calculating a missing chunk if there is any. Buffer map maintains the status of the chunk in the form of *1* and *0*. The parent peer $\boldsymbol{Pi \subseteq Np}$ sends the buffer map $\boldsymbol{B_{fi}}$ to the new peer.

$$B_{fi}[j] = \begin{cases} 1, & \textit{If chunk j exist in Buffer of peer i.} \\ 0, & \textit{otherwise} \end{cases}$$

Peer receives the buffer map of neighbor peer and finds the missing chunk. Buffer status of each peer is represented as: { C_k, C_{k+1}, C_{k+2} … C_x } where C_k is the initial chunk in the buffer map, and C_x is the last chunk received till now. Further, chunk C_{x+1} is the next chunk that the peer is waiting to receive. Periodically buffer map is exchanged between the peers to update the status if there are any significant changes in the network.

Scalable video coding (SVC) is used in our system. SVC is layered distributed video coding scheme. SVC is distributed into different layers from the layer set l as $\{l_0, E_1, E_2 \ldots\ldots E_n\}$. l_0 is a base layer; E_1 is the first enhancement layer and so on. The quality of the video is increased as layer go from the base layer to the enhancement layer. The base layer is the minimum requirement of a peer for viewing the video. Table 1 represents the nomenclature that is used in this paper.

Table 1: Nomenclature

Notation	Definition
T	Tracer Node
P	Set of all Parents Peer Servers
S	Set of Server
N_{bri}	Total Number of Neighbors for peer i
N	Maximum Number of Peers
v	Video id
B_{fi}	Buffer Map of peer i
l	Layer set
l_0	Base Layer
E_1	First Enhancement layer
E_n	Maximum enhancement layer
Ck	kth Chunk
level[P]	Level of peer P
list[P]	List of Best Available peers for peer p

4. New Hybrid Approach

Different overlay approaches which can be used in live video streaming in P2P network are discussed in this paper. These various approaches use different methods for creating an overlay in P2P network; some approaches use the stability of peer as a crucial factor, while some give priority to upload bandwidth of a peer, some authors have considered that geographical location is the prime consideration. Some authors try to combine the factors like geographical location and bandwidth. A new hybrid overlay approach has been discussed in our previous work [19]. This approach combined different crucial parameters which are very important for overlay construction. For stability of peers, age is calculated for each peer and the tree architecture is formed only with stable peers. Threshold value 'th2' is used for calculating the stability of each peer and time duration of the last session is considered as the age of the peer. If a peer is new and is coming in the network for the first time, then the average value of all the peers in the network is provided to that peer as its age. For creating the mesh overlay over tree overlay parameters like maximum upload bandwidth and age are used. Peers are distributed at different levels according to their upload bandwidth and age. Same range upload bandwidth peers come at the same level. If a peer has maximum remaining upload bandwidth and the age is also high than that peer forms the mesh overlay. Mesh overlay is formed between the same levels only. So the overall overlay is a hybrid overlay, but it is not full mesh. So the complexity of the hybrid overlay is less compared to the full mesh overlay.

When a new peer P enters the network, it sends a request to the tracer. The request tuple which is sent by P is < Upload Bandwidth, GeoLocation, Content, Age>. Tracer maintains the database of each peer and stores this information in that database. Tracer finds the list of the best available peer with its available data. First of all, tracer determines an appropriate level for a new peer. Algorithm 3 is used for calculating the level of new peer level[P]. According to content id the tracer finds the video which is required by the peer P, and after that the list of best available peers according to geographical location, upload bandwidth set of stable peer is sent to peer P. Algorithm 4 is used for calculating the list of best available peer i.e. list[P] [19]. Peer P sends the connection request to more than one peer from the list[P], and according to the reply from the peers, peer p connects in the overlay. After connection establishment between the peers, data transfer takes place according to the selected data scheduling approach. All the parameters (th1, th2, th3, age[pi], Max_P_N, level[pk],P_N, Bu[pk]) have the same meaning as described in our previous work [19].

This new hybrid overlay approach leverages the characteristics of both tree and mesh overlay. Tree overlay is created only using the stable peers in the network. So, the backbone of the overlay is its stable peers. Dynamic nature of the peer doesn't affect the new hybrid overlay approach because only stable peers are above in hierarchy as well as only stable peers are considered as parent peers for the other peers. Parent-child relation is established between the peers, so startup delay between the peers is less. There is high congestion in the mesh overlay as there are more control packets between the peers in the network. While in this new hybrid overlay the mesh is not full mesh, so the control packets are less, and the overlay is less complicated and congested. Bandwidth utilization of stable peer is also high in the new hybrid overlay, and the peers at the lower level can also use their upload bandwidth unlike that in tree overlay.

In this paper, we implement the new hybrid overlay approach as well as mesh overlay approach with some previously defined hybrid overlay methods. Four different overlay methods are implemented in this paper. The first approach is the Denacast approach (Mesh-Based overlay), the second is the hybrid overlay (Stable peer hybrid overlay), the third is a hybrid overlay (Bandwidth, geographical location based hybrid overlay), and fourth is this new hybrid overlay

approach. For simplicity, further, in this paper, we will refer to Denacast as Approach 1, Stable peer hybrid overlay as Approach 2, Bandwidth, geographical location based hybrid overlay approach as Approach 3 and New Hybrid overlay approach as Approach 4.

For verifying our results, we have chosen different parameters like start-up delay, the end to end delay, playback delay, frame loss ratio and packet drop due to an unreachable destination.

5. Simulation and Result

5.1 Simulation Setup

OverSim simulator is used for implementing the new hybrid overlay approach as well as mesh overlay approach with some previously defined hybrid overlay methods. OverSim provides an open source overlay for OMNET++ simulation environment (OS) in P2P network. For exchanging and processing the messages that are passed in OverSim, Discrete event simulation (DES) is used. This OverSim is divided into modules and NED (Network Description). A topology description language is used for defining the module; while C++ language is utilized for the purpose of doing processing between the modules [20]. Different parameters, which have been used for simulation, are given in Table 1.

Table 2: Simulation Parameters and Values.

S. No	Parameter	Value
1.	Simulation Duration	200s
2.	Average Video Bit Rate	512 Kbps
3.	Video Codec	SVC
4.	Buffer Map Exchange period	1 s
5.	Chunk Size	5 Frames
6.	Source Number	3
7.	Number of Runs	10
8.	Maximum Number of levels	6
9.	Average Chunk Length	130Kb
10.	Neighbour Notification Period	2s

5.2 Simulation Results

Overlay construction techniques directly affect the start-up delay. Start-up delay of new hybrid overlay approach is lower as compared to the other different overlay techniques like Denacast Approach (Mesh Overlay). The factors which affect the start-up delay are upload bandwidth, the stability of peers, and buffer management. Due to the stable structure of the overlay (parent-child relationship), the time required for a new peer to receive the desired frame is minimized so; start-up delay is also reduced. This new hybrid overlay considers stability as well as upload bandwidth of peers, so the start-up delay is lower compared to other approaches. Start-up delay of Denacast approach is maximum among the all other three methods due to the use of mesh overlay. Due to stable structure of overlay, approach 2 and approach 4 have less start-up delay while approach 1 and approach 3 have more start-up delay. If peers are unstable, it becomes difficult to maintain a parent-child relationship as; frequently finding new parents directly affects the start-up delay of the peer.

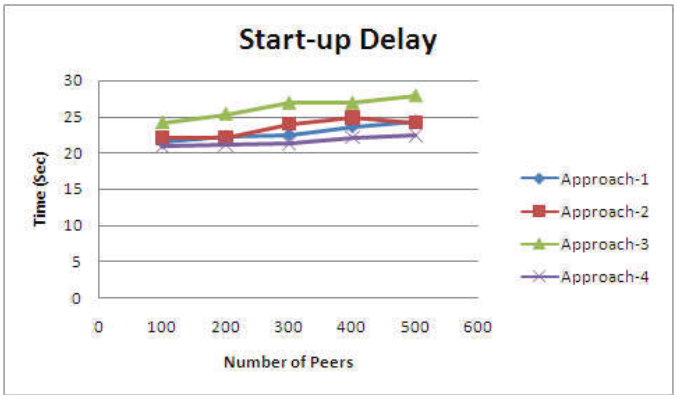

Figure 1: Average Start-up Delay

Apart from stable structure, upload bandwidth also plays a crucial role in minimizing the start-up delay. Due to which approach 4 has less start-up delay as compared to approach 2. Figure 1 shows a comparison of different approaches based on start-up delay. When there is less number of peers in the network all approaches approximately behave the same however as the number of peers in the network increases the start-up delay difference also becomes more.

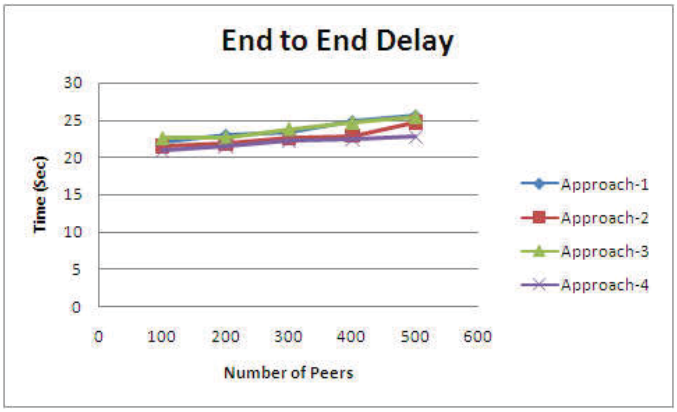

Figure 2: Average End to End Delay

End to end delay between peers is also a crucial factor for live video streaming in P2P network. If the peer is stable and the relation between the peers is predefined like (parent-child), then the end to end delay between the peers is also less. In approach 1 mesh overlay is used so the end to end delay between the peers is low while in approach 2 stable peers are used for overlay construction, so the end to end delay is less compared to approaches 1 and 3. The New hybrid overlay approach that we have proposed also uses the stable peers for overlay construction, and high upload bandwidth peers are above in hierarchy, and near to source

node so, the end to end delay of new hybrid overlay approach is less as compared to other approaches. Figure 2 shows that initially there are less number of peers, so there is less difference in the different approaches but as the number of peer increases, the end to end delay variation of different approaches also increases and the new approach behaves better than the other approaches.

Frame loss ratio of new hybrid overlay scheme is less compared to other approaches. The reason for frame loss in P2P network is less upload bandwidth and low stability of peers. If a parent peer is more dynamic, then there is more frame loss in the network. Also, the upload bandwidth and data rates between the peer affect the frame loss in the network. In approach 1, mesh overlay is followed so as the number of peer increases the number of the frame also increases, and due to instability and low resource utilization in the network, the frame loss ratio also increases as shown in figure 3. In approach 2, frame loss ratio is less compared to mesh overlay, but it is more compared to the new hybrid overlay. The frame loss ratio of new hybrid overlay lowers as the number of peers in the overlay increase.

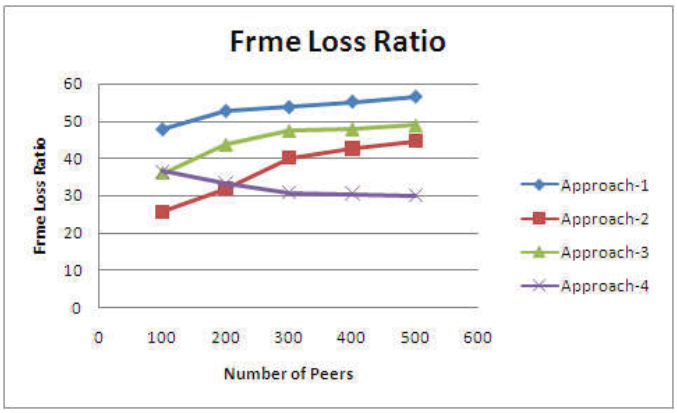

Figure 3: Average Frame Loss Ratio.

As the number of peers increases in the network distortion of the video also increases in Denacast and other hybrid approaches. When the number of peers is less in the overlay, then approach 2 and 3 behave well, and there is less distortion. But when the number of peer increases the amount of distortion also increases. The main reason for video distortion is frame loss or late arrival of the frame at the destination. In live video streaming, if a frame reaches the destination after its deadline then that frame is useless, and it just creates video distortion. The reason for the late arrival of frame or frame drop is the dynamic nature of parent peer or lack of upload bandwidth of the parent peer. Figure 4 shows that the distortion of new hybrid overlay approach is high when there is less number of peers in the network. However, as the number of peers in the network increases it starts to reduce due to more stable peers and upload bandwidth in a particular area.

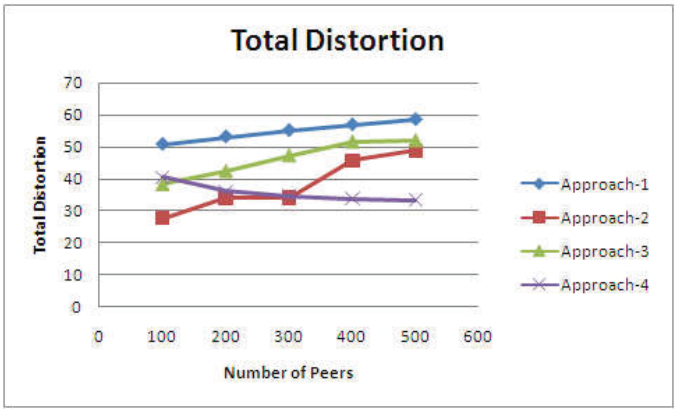

Figure 4: Average Total Distortion.

Playback delay of the new hybrid overlay is more as compared to other approaches as the number of peers is less. However, as the number of peers in the network increases playback delay of new hybrid overlay withers approximately same as the Denacast or less than other hybrid overlay approaches. So, the performance of the overall network is affected by overlay construction, and this new hybrid overlay approach increases the network performance.

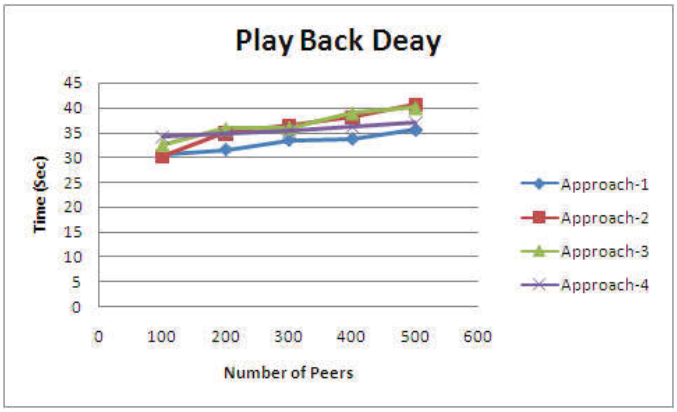

Figure 5: Average Play Back Delay.

6. Conclusion

Overlay construction is one of the principal issues among the various other challenging issues that affect the performance of live video streaming in P2P networks. This paper discusses the different overlay construction approaches, and a comparative analysis is presented. Due to the drawbacks of various overlay methods which are addressed in this paper, there is demand for a new overlay construction approach. We implement the different hybrid overlay methods, Denacast approach, and new hybrid overlay approach. New hybrid overlay approach leverages the characteristics of both tree and mesh overlay. For creating a new overlay approach various crucial parameters that have a significant role in overlay construction are used like, the upload bandwidth, stability of peers (age) and geographical location. With the help of simulation results on different QoS parameters such as the end to end delay, start-up delay,

playback delay, distortion and frame loss ratio we demonstrate the performance of different approaches. For less number of peers in an overlay, all approaches approximately behave the same, however, as the number of peers in the overlay increases the performance of new hybrid overlay approach is predicted to be better as compared to the other existing approaches.

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