A Comparative Study of Tree-based and Mesh-based Overlay P2P Media Streaming

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Abstract

Streaming media technology has seen tremendous growth and is currently a popular research area. While most of the work on streaming media technology is on ensuring the quality of the video playback and the scalability of the overall media streaming solution, there are few researches that are being conducted to address the limitations of the network, computer hardware nor the streaming media characteristics. These are the other factors that causes network capacity bottleneck. It is generally accepted that a Peer-to-Peer network is suitable for streaming media network and these can be classified into two main network architectures; a tree-based architecture and a mesh-based architecture. In this paper, we investigate and evaluate the network limitations between a Peer-to-Peer tree-based architecture and the more popular mesh-based architecture for media streaming performance. The simulations were conducted under various real-world scenarios and evaluated using different critical performance metrics that affects the reliability of the streaming quality and performance.

Keywords: *Peer-to-Peer, media streaming, mesh-based, tree-based*

1. Introduction

In recent years, with the proliferation of high speed networks, there is an explosive growth in Internet data traffic especially video related traffic. Cisco forecasted by 2015, there will be more than 15 billion devices connected to the global Internet [1]. In the same press release, Cisco predicted 1 million video minutes, which is equivalent to 674 days will traverse the Internet every second. Hence, the conventional solution of client-server video streaming model, which allocates servers and network resources to each client request, is unable to provide reliable service due to the scalability constraints. This is because media streaming demands a high transmission rate and causes heavy loads on server whenever there is an increase in the client streaming requests. Peer-to-Peer (P2P) is a viable streaming model that is able to overcome the setback and bottleneck of centralized streaming server due to its distributed design and architecture. The most common P2P architecture that is widely used is the P2P overlay network (Figure 1). A P2P overlay network is a type of overlay network that is a distributed system in nature without any hierarchical organization or centralized control. Peers form self-organizing overlay networks on the Internet Protocol (IP) networks. Each node in a P2P overlay network simultaneously functions as both a client and a server to the other nodes in a network.

In terms of distributing large amount of data over the Internet, BitTorrent [2] (a P2P file sharing protocol) has shown tremendous success and managed to inspire the usage of similar file sharing model for P2P media streaming [3-6]. In a P2P media streaming network, nodes that have all or part of the requested media can forward it to the connected requesting nodes. Each node contributes its own resources which result in the capacity of the whole system grow when the number of nodes increases. P2P streaming network is able to manage dynamically the available resources in the networks since P2P networks scale with the number of peers in the system.

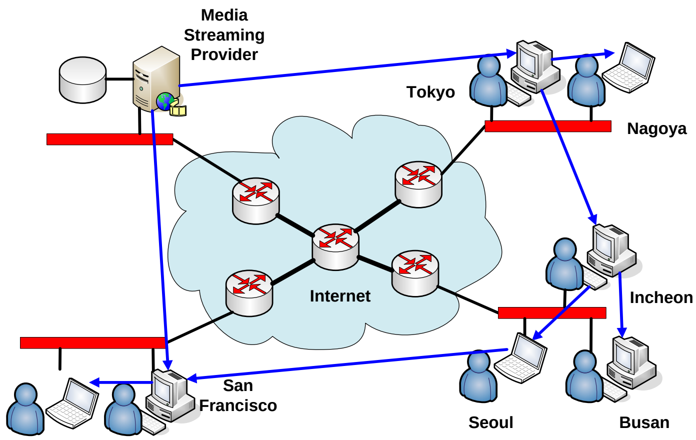

Figure 1. P2P Overlay Network

Generally, P2P media streaming architectures are classified into two main categories: (1) Tree-based topology and (2) Mesh-based topology. Tree-based P2P streaming is an extension of tree-based multicast system. In this system, a peer is either an interior node or a leaf node. Participating peers are organized into multiple diverse trees. On the other hand, mesh-based P2P streaming approach is inspired by BitTorrent file sharing protocol where participating peers form a randomly connected mesh. Similar to BitTorrent mesh-based network, the overall network utilization is high and newly connected peers are discover at rapid pace via message passing or gossiping amongst connected peers. Both architectures used different algorithm to discover new peer, recover lost transmission from the impact of peer churn and select neighbour to transfer the video frames.

In this paper, we attempt to investigate and evaluate the performance P2P media streaming for both tree-based and mesh-based architectures. The rest of this paper is organized as follows; In Section II, we summarized the works that have been done by previous researchers. Then in Section III, we describe the model, simulation setup and implementation, followed by the results and discussions in Section IV. Finally, we conclude our findings in Section V.

2. Related Works

In most cases, a P2P network can be classified based on organization of connected peers, namely structured network or unstructured network. A tree-based architecture is structured network whilst a mesh-based architecture is unstructured network.

Figure 2 illustrates a common tree-based topology, where there is only a single delivery path from the streaming media source to any other connected peers. Figure 3 shows a mesh-based topology where each peer in the network is connected to other peers in the network. In mesh-based topology, there are multiple delivery paths from the streaming media source to any other peers.

2.1. Tree-based Architectures

Tree-based P2P media streaming topology is an extension of single-tree multicast routing in which one overlay routing tree rooted at the server is constructed and maintained on the top of all the nodes in a system. [7] Each node pushes data it receives to a number of other nodes. A node that forwards data is called a parent node, and a node that receives it, is a child node. Each node in the tree can have as many children as its capacity with respect to the streaming rate allows. The tree construction and the parent-child relations are determined by factors such as the end-to-end topology. Generally, a packet sent out from the streaming media source to its children in the first layer and they push it to their child-peers in turn until all the peers in the tree receive it.

Due to the nature of tree-based which is structured network, the impact of high churn rate will drastically affects the performance of the P2P media streaming system. Multiple tree-based [7] overlay architectures are proposed to resolve the strong dependency of a peer on all its parent peers in architectures based on a single tree.

2.2. Mesh-based Architectures

The mesh-based overlay media streaming architecture is an unstructured approach where network is not constructed or maintained any explicit structure data delivery. [8, 9] In terms of peers organization, there is no static topology and peers establish peering relationships dynamically according to the data availability. In contrast to structured network, which constantly repairs its structure in a highly dynamic P2P environment, the data availability among peers guides the peer relationships for mesh-based streaming model. The mesh-based architectures also sometimes referred as the data-driven approach. [4]

For a mesh-based streaming model, participating peers form a randomly connected overlay. Each peer tries to maintain a certain number parent nodes and also at the same serves a specific number of neighbor peers. Peers upload or download the content from multiple neighbours upon data availability. In the case of the departure of a neighbor, peers can still get the content from remaining neighbors. During video streaming session, the peers will continue to discover new peers to establish new peering relationships. Since each peer maintains its own neighborhood dynamically, the mesh-based approach is very robust against peer churn. In mesh-based, every node needs to obtain info on which chunks are owned by its peers and explicitly “pull” the chunk it needs. Peers exchange buffer maps with neighbor peers during the “pull” process. Mesh based system offers better resilient to node failures as each node relies on multiple peers to retrieve streaming content [4].

Since a mesh overlay does not maintain a parent-child relationship during routing of the data blocks, mesh-based architectures have various disadvantages for whenever data blocks needed to be pulled from neighbors. As a result, more delays as well as significant increase in control overheads, *i.e.*, sending control notifications to every data block received at a peer. Lastly, mesh-based topology requires large buffers to support the chunk pull from neighbor peers.

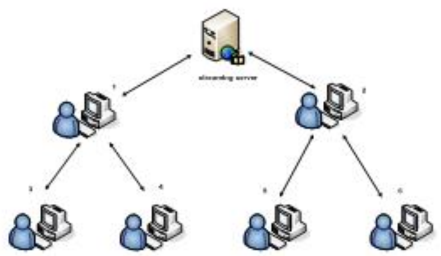

Figure 2. Single Tree-based Topology

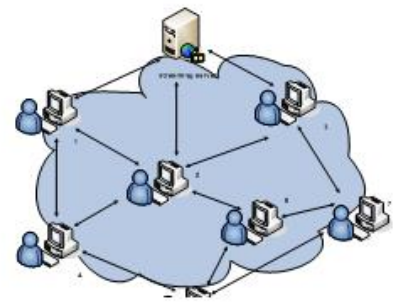

Figure 3. Mesh-based Topology

3. P2P Streaming Models

In order to investigate and evaluate the performance for both tree-based P2P streaming model and mesh-based P2P streaming model, we construct both topologies using discrete event network simulator, OMNET++ [10]. We construct both architectures for P2P streaming networks which consist of peer discovery, peer selection and peer replacement protocols.

3.1. Peer Discovery

The main purpose of peer discovery protocol is to find the information about other connected peers in a P2P streaming network, when a peer initially joins the network. Based on the peer information obtained, it will be used to select appropriate neighbour peers for a peer. Generally, there are two general peer-discovery methods: (1) **Global Peer Information**: maintains the global peer information and keep only the information about a small list of peers. (2) **Peer Discovery Method**: which maintains the information for only a small list of peers can be further classified into categories: flooding-like method and gossip-based method. [11]

In networks based on the flooding-like method, a peer basically send a simple probing message first to a starting peer, and then the message will be flooded down to its neighbors and their neighbors until it finally found a suitable point to join the network. In contrast, for gossip-based method, peer maintains the information about a small list of randomly selected peers which is initially obtained from a starting peer. The information is updated periodically vis-à-vis messages exchanges with others peers in the list. Compared to global peer information method, the gossip-based method shows better scalability, and is suitable for large-scale P2P streaming networks.

3.2. Peer Selection

Peer selection protocol is basic for a P2P streaming network where it directly determines the performance of individual peer and the overall network. In order to achieve a reliable media streaming, peers are usually selected to achieve the followings: 1) to be more resilient to peer churn and network dynamics, 2) to minimize packet delay and 3) to achieve a minimum of total streaming rate required at a peer. Generally, P2P overlay network consists of peers with large number of shared links or shared parent and children peers, and it performs worse in dynamic network environments. Hence, peers should consider selecting some resilient nodes as their parents according to some standards in order to be more resilient to peer churn and network dynamics

3.3. Peer Replacement

If a peer leaves the system without notification, the streaming of the media will be disrupted at the descendant peers of the missing peer and the routing structure of the network is weakened, especially in tree-based networks. The extent of disruption depends on the number of descendant peers connected to the missing peer. Therefore, a new parent peer may be selected for each child node of the departed peer. There are two approaches are available to replace a peer: 1) **Reactive**: when a peer leaves the network, or a peer failure has occurred, the connectivity of the network is retained by assigning a new parent peer to each child of the missing peer. 2) **Proactive**: the restoration plan for the descendant peers of the missing peer is carried out before the peer leaves the network. Whenever a peer fails or leaves the network, this will lead to a broken path being formed. As a result, a new path is selected from the backup sets to replace the broken path thus restoring the connectivity of the network.

4. Result and Discussions

In order to investigate and evaluate the media streaming performance for both tree-based P2P media streaming model and mesh-based P2P media streaming model, we conducted the simulations under various scenarios using discrete event network simulator, OMNET++.

4.1. Simulation Configurations

Simulations were configured with different network sizes, peer churn and number of neighbors. For simulating valid video stream, we used Star Wars IV trace file which can be obtained from Video Trace Library [12]. By varying different simulation configurations, we conducted simulations which were repeated for 5 times. We tabulate the results and calculate the average all the peer's output for each scenario. Table I shows the simulation parameters used for both mesh-based and tree-based media streaming simulations.

For simulations with dynamic churn scenario, peer removal probability was set to 1 in order to examine the peers leaving frequency impact on the performance of network when there is no new peer added/replaced into the network. Minimum number of remaining peers is configured as half of the initial peer's number after the reduction of peers during the streaming process. This is ensure that there are sufficient peers to deliver the video to all peers till the simulation process comes to end.

Table 1. Simulation Parameters

Maximum packet size	1 Kbytes
Peer side buffer	40 seconds
Buffer map exchange period	5 seconds
Video codec	MPEG4 Part I
Video FPS	30
Number of frames in GOP	12 frames
Selected trace file	Star Wars IV
Average video bitrate	512 Kbps
Start-up Buffering	8 seconds
Source Bandwidth	6Mbps
Number of neighbours	(2 , 4)
Simulation duration	250 seconds

4.2. Performance Metrics

The following performance metrics were measured for both tree-based streaming model and mesh-based models:

1. **End-to-end delay**: the time between the video message created at the source and time for the video frame reaches the client node.
2. **Frame Loss ratio**: the ratio of the dropped over the video frame transmission.
3. **Playback delay**: defined as the time elapsed from the instant in which the source provides the content to the instant in which a client reads it from the peer's playout buffer.

4.3. Simulation Results

Figure 4 shows the average end-to-end delays among all peers. Overall, tree-based approach has lower end-to-end delay compared to mesh-based approach. In tree-based approach, the parent nodes keep pushing the video data down to their child nodes and this pushing method considerably speeds up the video delivery rate. For mesh-based approach, pull strategy is used where each node needs to send the request to their neighbor nodes in order to receive the requested frames from neighbor nodes.

We also evaluated the effects of dynamics of peer churn towards the content delivery. Based on our simulation results (Figure 4, 5 and 6), peer churn adversely affect the larger peer group size. It is noted that the dynamics churn shows higher delay rate than the static churn in between 200 nodes larger network. While in tree-based approach, a child node is able to find a new parent node easily in a smaller peer group size after its former parent node leaves

Figure 5 depicts the frame loss ratio for both models with the increase of network sizes. The tree-based model has lower frame loss compared with the mesh-based model. In tree-based approach, all the nodes are constructed via parent-child relationship. Thus, nodes have stable frame source and the push mechanism guarantee the data is transferred from the parent to their own child node. However, in dynamic peer churn environment, mesh-based architecture has lower frame loss ratio than the tree-based. Every node in mesh-based topology is able to request the frames from more neighbors when the network size increases. With more frame suppliers, there will be less frame loss and this guarantees the smoothness of video delivery.

Figure 6 shows the playback delay experienced by both topologies under static churn and dynamic churn. The tree-based approach exhibits lower playback delay across all peer group sizes. Push mechanism in the tree-based architecture is more effective to reduce the playback delay compared to the pull mechanism in mesh-based architecture. In mesh-based approach, the playback delay increases with the network sizes. When there are more peers in the network, the longer path which the frames need to transfer from the streaming source to the playout buffer of the destination node.

For both topologies with dynamic churn environment, mesh-based architecture has lower playback delay as the network size increases. Overall, node has smoother playback continuity due to the increase of frame suppliers' increase. Nodes in mesh-based network can make new connection much easier to neighbor nodes whenever neighbor nodes leave the network. In tree-based approach, leaving nodes causes increase playback delay as the remaining child node needs to find a replacement parent node or new path for the video delivery.

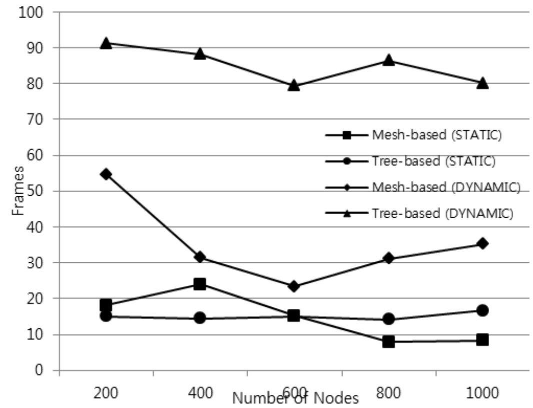

Figure 4. End-to-end delays for both Static and Dynamic Mesh-based & Tree-based Topologies

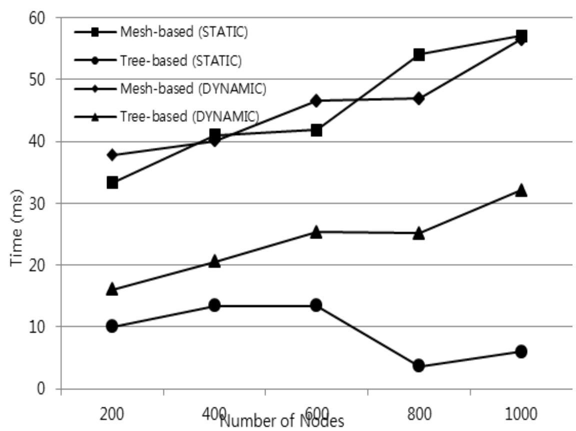

Figure 5. Frame loss ratio for both Static and Dynamic Mesh-based & Tree-based Topologies

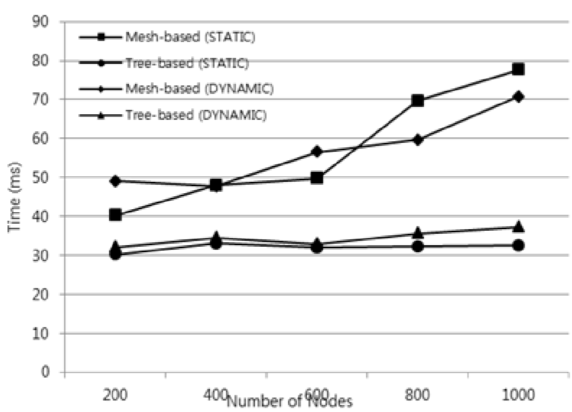

Figure 6. Playback Delay for both Static and Dynamic Mesh-based & Tree-based Topologies

5. Conclusion

In this paper, we investigate and evaluated the performance for both tree-based and mesh-based streaming architectures. Simulations were conducted for both architectures under static and dynamic of peer churn scenarios. Both streaming architectures were evaluated using performance metrics: end-to-end delay, frame loss ratio and playback delay. Simulation results show that both streaming models demonstrate their strengths and weaknesses under various scenarios. Tree-based model has more stable video delivery quality, low playback delay and end-to-end delay. However, under dynamic peer churn, the peer replacement and recovery mechanism require time consume for peer replacement. In contrast, mesh-based approach is more resilient toward dynamic peer churn environment, and peers have more resources to choose frame suppliers with increase in the size of network increases.

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