Challenges of P2P Streaming Technologies for IPTV Services

Yennun Huang,
Yih-Farn Chen,
Rittwik Jana,
Bin Wei

AT&T Labs
180 Park Avenue
Florham Park, NJ 07932

Michael Rabinovich

Electrical Engineering & Computer Science
Case Western Reserve University
Cleveland, Ohio 44106

Zhen Xiao

IBM T. J. Watson Research Center
19 Skyline Drive
Hawthorne, NY 10532

ABSTRACT

This paper studies the advantages and potential problems of P2P streaming technology for IPTV services over DSL or cable modem broadband access networks. We present an analysis which shows that applying P2P streaming technology on a DSL or cable modem access network may overload switches and routers of the network so that the number of viewers who can receive videos in good quality may actually be reduced. From the study, we conclude that P2P streaming technology for IPTV services is beneficial only when the north link of a DSL/cable modem switch or the south links of a local video serving office are the bottlenecks.

Keywords

IPTV, P2P, Content distribution network, FTTN, Multimedia, Streaming, Video-on-Demand

1. INTRODUCTION

Internet protocol TV (IPTV) promises to offer viewers an innovative set of choices and controls over their TV content. Two major U.S. telecommunication companies, AT&T and Verizon, have recently announced significant investments to replace the copper lines in their networks with fiber optic cables for delivering many IPTV channels to residential customers. Similar investments and interests are also happening in Europe and Asia. Major cities in Japan, for example, already provide high-speed networks which allow customers to obtain video over IP.

A viewer can receive IPTV videos in good quality if the available downlink bandwidth of the viewer is greater than the video encoding bit rate. To provide sufficient bandwidth for IPTV services for each home, service providers are using high speed xDSL or cable networks to deliver video content to viewers' set-top boxes. As an example, LightSpeed (an AT&T IPTV service) uses Fiber-to-the-Neightborhood (FTTN) Networks, and the network architecture of LightSpeed consists of a small number of national (or regional) super head-ends and a large number of local video serving offices. The super head-ends serve as the redundant national content aggregation points for video on demand encoding. The regional video hub offices provide aggregation and storage of local content. It serves as a Video-On-Demand (VOD) library for local video serving offices, which in turn distribute video content to the customers. Such an IPTV service provides customers flexible content choice and VOD capabilities integrated with the latest compression and digital rights management (DRM) technology.

VOD is an interactive multimedia system that works like cable television, the key difference is that the client can select a movie from a centralized video store. Individual clients are able to watch different programs when they wish to, making the system a realization of the video rental shop brought into the home. Compared to traditional cable TV, one major advantage of IPTV services is that IPTV provides an almost unlimited number of VOD programs. However, providing VOD for a large number of viewers creates very difficult technology challenges on both system and networking resources. Supporting VOD efficiently on IP networks has been a research topic for quite some time. To implement a VOD system, the simplest solution dedicates an individual connection to stream the content to each client. This method consumes a tremendous amount of costly bandwidth and leads to an inferior quality stream for the client, making it nearly impossible for a service provider to serve quality streaming to large audiences while generating profits [7], [8], [14].

One solution to the problem of high deployment and maintenance cost is to use a peer-to-peer (P2P) communication system. In such systems, end users (i.e., peers) interested in data sharing participate as both clients and servers, typically through an application overlay network. When a user locates interesting data from another user, the downloading happens directly between the two without going through a central server. While early P2P systems are mostly used

IPTV Workshop International World Wide Web Conference, May 23, 2006, Edinburgh, Scotland, United Kingdom

for file downloading, recently there have been several efforts on using the peer-to-peer approach to support live streaming [3], [6], [10], [11], [14] and VOD streaming,[1] [4], [5], [9]. The P2P approach avoids the deployment problem of IP multicast service as well as the bottleneck at the video servers.

However, existing P2P streaming/downloading platforms like Skype [18], Kontiki [17] Swarmcast [16] do not consider the constraints of the underlying service infrastructure such as the capacity of access network switches (e.g. DSL or cable modem), or the available throughput of streaming servers. These constraints must be taken into account in IPTV service environments where P2P video streaming could saturate the available uplink bandwidth of each peer and overload the xDSL switches. By considering the underlying network infrastructure, we show that under certain network conditions, P2P video sharing is actually harmful - that is, using P2P streaming results in fewer number of viewers who can receive good quality videos, compared to a solution using a centralized Content-Distribution-Network (CDN).

The rest of the paper is organized as follows. We start with an overview of related work on P2P streaming service, followed by an introduction to the challenges of P2P IPTV services. A P2P network model is established that later help to setup the constraints of sharing within a community and in a local office.

2. RELATED WORK ON P2P STREAMING SERVICES

This section highlights some of the more popular P2P streaming services that are successfully deployed on the Internet.

Swarmcast Rather than dealing with whole files or with streaming solutions, Swarmcast uses the P2P network to divide very large files into small (32K) packets. Using forward error correction (FEC) encoding, Swarmcast randomly requests packets from the machines that are hosting the content. Swarmcast enables users to cooperate in a distributed grid to provide fast downloads over broadband networks. The original Swarmcast technology required that files be fully downloaded and decoded before the files could be used. Recently, Onion Networks has introduced Swarmstreaming^{TM}, which allows streaming or progressive playback of media files. This means that users can watch videos while they are still being downloaded. [16].

Kontiki - Kontiki Grid Delivery Technology^{TM} is the industry's first commercial solution based on grid computing concepts, with over 18 million nodes served and 90% greater network efficiency [17]. Kontiki employs a secure grid of PCs and servers, which deliver content with a high level of network efficiency and centralized control. In grid delivery, content is delivered to a user not only from the server where it originates, but also from any number of network-connected computers that also have copies of the requested content. The Kontiki system dynamically optimizes delivery from many PCs and media servers by caching content at the very edge of the network. This creates network efficiency gains of 10 to 25 times over traditional approaches.

The Kontiki Grid Delivery technology employs several bandwidth harvesting techniques.

- **Time shifting** : Kontiki servers schedule certain media deliveries at off-peak hours to smooth out bandwidth usage over the day.
- **Adaptive Multirate Serving** : Kontiki allows a client to open multiple connections to several servers to request small parts simultaneously. Moreover, the network will automatically optimize its requests to focus on the computers which have the least number of hops with congested connections.
- **Outer Edge Caching** : Kontiki forms a relay cache in which each computer receiving a file passes it on to others who need it as well. It allows smooth downloads for end users while reducing the demands on bandwidth for ISP's and content servers.

Skype - Skype^{TM} is a free P2P VoIP service, which also does video conferencing via the use of a third-party plug-in from vSkype [18]. vSkype allows Skype users with a connected webcam to make video calls via the Skype client. The system has a generally favorable reputation for working across different types of network connections (including firewalls and NAT) because voice packets are routed by the combined users of the free desktop software application. This technology was designed to support groups and other add-on services such as sharing. It has built-in QOS and constantly adapts to fluctuating bandwidth and prioritizes multiplexed data accordingly. It also provides centralized bandwidth control for shared connections. The multipoint architecture scales to support large groups of up to 200 per call.

P2P Streaming Research. There is vast research literature on P2P streaming. Unlike existing research that concentrates on delivery over an overlay network of peers (e.g., [13]), we consider P2P delivery directly over the physical network and take into account capacity limitations of the underlying physical network infrastructure. One consequence of this new approach is the insight that P2P delivery of IPTV is mostly beneficial within one DSL or cable modem community, and is in fact often detrimental to scalability when done across communities. Hefeeda et al. present a cost-profit analysis of a media streaming service deployed over a peer-to-peer (P2P) infrastructure [19]. They also consider the limited capacity as well as the heterogeneity of peers in the analysis. The analysis shows that with the appropriate incentives for participating peers, the service provider achieves more profit. In addition, the analysis shows how a service provider can maximize its revenue by controlling the amount of incentives offered to peers. However, their analysis did not consider the bandwidth constraints of the underlying infrastructure elements.

3. CHALLENGES FOR P2P IPTV SERVICES

There are several challenges for providing IPTV services, some of which are outlined below.

Ensuring quality of service. Some IPTV services are provided over the public Internet, where the available bandwidth can fluctuate dynamically due to network conditions. This makes it difficult to provide a reliable quality of service for Internet streaming sessions, which may have a long duration and require significant amount of network bandwidth. Other IPTV services are delivered through a dedicated network, such as a cable, DSL or fiber network connecting each home. Even so, resource allocation for VOD services and resource sharing with other applications (such as VoIP) remains a challenge.

P2P benefits analysis. As we discussed at the beginning of the paper, P2P technologies have become a popular approach for scalable delivery of multimedia content. In the current broadband home networking architecture, the communication between two IPTV viewers might traverse the local switches (such as local cable headends). Depending on the constraints of the network, it may actually decrease the number of IPTV viewers that can be supported. While previous work has touted P2P technologies in multimedia delivery, one major challenge is to perform a rigorous analysis of the specific conditions where P2P streaming can increase the number of concurrent viewers.

Another challenge is how to do video compression. Uncompressed video can take a prohibitive amount of network bandwidth to transmit. Recently, various compression algorithms have been developed to reduce the amount of bandwidth consumption. The serving capacity of xDSL/CMTS switches are limited as well (see the AT&T LightSpeed project as an example). Careful planning is needed to scale the service to millions of customers.

Incentives and billing models. In order to encourage viewers to make their set-top boxes or other viewing devices available for P2P streaming, some incentives may be given to peers who upload video data to other peers from their own set-top boxes. Some P2P systems such as KaZaa and eMule use participation levels or credit/reputation systems to track the contribution of each peer, and encourage peers to contribute by giving higher service priority to those peers with more contribution. However, such systems are either too complex and unrealistic or very easy to be cheated and misused. BitTorrent uses "tit-for-tat" incentive mechanism to prevent *free riding* effectively so that peers with high upload bandwidth have corresponding high download bandwidth. For IPTV services, a system can adopt a "built-in" incentive model where the P2P algorithm is implemented in the set up box of each IPTV user. The incentive is not given explicitly in this case, and P2P sharing is hidden from viewers. It can also use a "reward" based model where a home user can sign up for P2P sharing of its video in order to save her monthly bill. The amount of savings could depend on the amount of bytes being uploaded from her set-top boxes. One challenge in the P2P IPTV service is to find out an incentive which can attract more people to share but at the same time increase the revenue for the IPTV service provider.

Practical P2P platform implementation. Streaming content may be encoded and compressed using a proprietary coding or digital rights management (DRM) scheme. Therefore, integrating various content blocks from various peers on the fly for a proprietary IPTV system is a very difficult task. Also, IPTV servers and players use a proprietary streaming protocol to exchange status and control the streaming bit rate. Adding P2P streaming components to a proprietary IPTV infrastructure may interfere with the streaming protocol. As a result, seamless implementation of P2P streaming technology on a proprietary IPTV infrastructure such as the Microsoft IPTV platform is a big challenge.

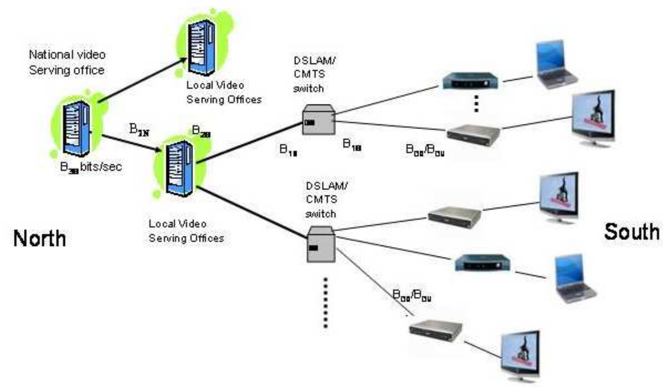

Figure 1: System Model

In the rest of the paper, we focus on the second challenge - that is, analyze the network conditions when P2P streaming can increase the number of viewers who can receive good quality of video services, compared to a centralized client-server streaming mechanism.

4. NETWORK MODEL FOR IPTV SERVICES

As shown in Figure 1, video streaming servers are organized in two levels - a local video serving office which consists of a cluster of streaming servers or proxies to serve viewers directly and national (or regional) offices which can distribute videos to local serving offices based on existing policies or on demand. We consider both video on demand and live broadcast. Each local office connects to a set of DSLAM switches or cable modem termination system (CMTS) switches through optical fiber cables. Each switch connects a community of IPTV service customers through twisted-pair copper wires.

A community consists of all homes which are connected to the same DSLAM or CMTS switch. The uplinks (north-links) of service routers in the local office connect to national offices by high-speed optical fiber networks. The parameters used throughout the paper are shown in Table 1.

Example 1 : AT&T Project LightSpeed
In the first phase of AT&T project LightSpeed, each home is allocated $22M$ bps download bandwidth ($B_{0D} \leq 22M$ bps) and $1M$ bps upload bandwidth ($B_{0U} \leq 1M$ bps). LightSpeed uses the Alcatel 7330 ISAM FTTN (DSLAM) switch, which has $24G$ bps downlink switching capacity ($B_{1S} \leq 24G$). Each FTTN switch can connect an OC-24 fiber to a service router in a local video office ($B_{1N} \leq 1.244G$ bps).

parameters	explanations
B_{0D}	Download bandwidth into a home
B_{0U}	Upload bandwidth out of a home
B_{1S}	Total capacity of south-bound links (downlinks) of a DSLAM/CMTS switch
B_{1N}	Capacity of the north-bound link (uplink) of a switch. Determined by the total bandwidth of uplink fibers from a switch to a local office and the switching capacity of the service router in a local office.
B_{2S}	Maximum throughput in a local office, is determined by capacities of service routers, optical network cables and/or streaming servers in a local office.
B_{2N}	Maximum capacity of the north-link of service routers in a local office.
u	Average streaming bit rate for a video. Must be at least the video encoding bit rate.
k	Maximum number of concurrent viewers supported by a switch. From the above definition, k is less than or equal to $min(B_{1N}/u, B_{1S}/u)$.
b	Fraction of viewers in a community who get videos from peers, not from a local office.
n	Maximum number of communities connected to a local video serving office.
N	Maximum number of concurrent viewers supported by a local office. Equal to nk.
S_c	Number of viewers who receive videos from peers within the same community.
S_a	Number of viewers who receive videos from peers in other communities.

Table 1: Parameters used

The service router (e.g. Alcatel 7550 SR) in a local video office could then connect an OC-192 fiber ($B_{2N} \leq 10G$) to national video serving offices. The switching capacity of a service router in a local office is $200G$ bps. Note that B_{2S} is also constrained by the total throughput of the streaming servers in a local office. As an example, one study [22] showed that an HP Proliant ML 530 G2 server running Windows server 2003, configured with dual 2.4GHz Intel Xeon processors, 4G of RAM and four Compaq Ultra SCSI 15,000 RPM hard disk drives, has a maximum throughput of $1G$ bps. If a local office has a cluster of 100 such servers, $B_{2S} = 100G$ bps. Each high-definition (HD) channel uses 6M bps bandwidth and each standard-definition (SD) channel uses 2M bps bandwidth. Each FTTN switch is designed to support up to 192 concurrent viewers ($k = 192$).

5. NETWORK CONSTRAINTS FOR CONVENTIONAL IPTV SERVICES

To provide a good-quality IPTV service, the following network conditions must be met. First, the download bandwidth to the home must be greater than the HD streaming rate: $B_{0D} \geq u$. Second, the downlink and uplink bandwidths of a DSLAM/CMTS switch must each be able to support k concurrent viewers in a community: $B_{1S} \geq uk$ and $B_{1N} \geq uk$. Third, the total number of communities served by a local office is bounded by the total downlink throughput in a local office: $B_{2S} \geq nB_{1N} \geq nku$ or $n \leq B_{2S}/(ku)$. Fourth, the maximum number of concurrent viewers supported by a local video office is nk.

The traffic on the uplinks of a local office (bounded by B_{2N}) depends on the video distribution policy used by an IPTV service provider. To reduce the load on the national offices, popular videos are distributed to local offices during off-peak hours. In this case, an IPTV service administrator can apply a distribution policy where the most popular videos are available in local video offices so that the uplinks of local video offices will not become a bottleneck.

6. NETWORK CONSTRAINTS FOR P2P STREAMING

6.1 P2P Sharing within a Community

To simplify the discussion, the constraint analysis concentrates only on none-or-all case. Each peer gets data entirely from either the server or peers. The task of serving video streams on a P2P network can be shared by several peers. However, the analysis presented here can be easily extended to the case where a viewer can get part of a video from his/her peers or part from the local video office server.

First, let's consider P2P sharing among peers within a community. In this case, among k concurrent viewers in a community, S_c (i.e. kb viewers) of them will get videos from peers within the same community, and $k - S_c$ will get videos from servers. P2P viewers get video from peers in its community, so the uploaded P2P video traffic is uS_c. Therefore, the total traffic generated by P2P sharing for the south-links (downlinks) of a DSLAM/CMTS switch is $2S_c$. In this case, the capacity of the southbound links (downlinks) of a switch must be greater than the sum of video streaming traffic $(k - S_c)u$ coming from video servers and the total P2P video traffic, $2S_cu$.

From the above discussion, the following conditions must be satisfied for good quality IPTV services:

Constraint 1 :

$$\begin{aligned} B_{1S} &\geq (k - S_c)u + 2S_cu = (k + S_c)u \\ &= k(1 + b)u \end{aligned}$$

Constraint 2 :

$$\begin{aligned} B_{1N} &\geq (k - S_c)u = k(1 - b)u \\ B_{2S} &\geq n(k - S_c)u, \text{ or } n \leq B_{2S}/[(k(1 - b)u)] \\ N &= nk \leq kB_{2S}/[(k(1 - b)u)] \end{aligned}$$

Given the increased upload traffic, P2P sharing within a community may or may not be feasible if the downlink bandwidth of a DSLAM/CMTS switch is the bottleneck. However, P2P sharing decreases the load on the uplinks of the switches as shown in Constraint 2. Therefore, P2P sharing for IPTV within a community will have the most benefit if bandwidth is constrained on the uplink portion of a DSLAM.

6.2 P2P Sharing in a Local Office

Let us then consider P2P sharing among all peers in a local office. In the second case, we consider P2P video sharing among all viewers served by a local office. Within a community, S_c viewers get all their videos from peers within the same community and S_a viewers get the entire or part of their videos from peers in other communities, where $S_c + S_a = kb$. The maximum traffic in the uplink of a DSLAM/CMTS switch occurs when each of the S_a viewers get its entire video from peers outside its community. To maximize the capacity of a local office, we balance the video sharing traffic among peers in all communities. When an equilibrium has been reached, each community will upload $S_a u$ bps to other communities and receive $S_a u$ bps from other communities for P2P video sharing. Thus, the total video streaming download traffic in the uplink (north link) of a switch is $(k - S_c - S_a)u$ bps coming from the local office servers and $S_a u$ bps coming from peers in other communities while the upload traffic is $S_a u$ bps to support peers in other communities. Therefore, in balance, the total traffic on the uplink of the switch is $(k - S_c - S_a)u + 2S_a u$.

From the above discussion, the following constraints must be satisfied to guarantee good quality service:

Constraint 3 :

$$\begin{aligned} B_{1S} &\geq (k - S_c - S_a)u + 2S_c u + 2S_a u \\ &= (k + S_c + S_a)u \geq k(1 + b)u \end{aligned}$$

Constraint 4 :

$$\begin{aligned} B_{1N} &\geq (k - S_c - S_a)u + 2S_a u \\ &= (k - S_c + S_a)u \geq k(1 - b)u \\ B_{2S} &\geq n(k - S_c - S_a)u + 2nS_a u \\ &= n(k - S_c + S_a)u, \text{ or} \\ &\quad n \leq B_{2S}/[(k - S_c + S_a)u] \\ N &= nk \leq kB_{2S}/[(k - S_c + S_a)u] \end{aligned}$$

From the constraints, increasing P2P sharing among peers across all communities (i.e. increasing S_a) increases the traffic on both the uplink and the downlinks of a DSLAM /CMTS switch, but reduces the load on the uplink of a local office. So, if B_{2N} is the bottleneck, applying P2P technology for peers in all communities of a local office is beneficial. However, even in this case, an IPTV service provider could apply other content distribution technologies (i.e. caching or replication) to distribute video files from national offices to the local offices to reduce the load on the uplink of the local office. So, P2P sharing among all communities may not be needed.

6.2.1 Bottleneck Observations

From the analysis of the above three cases, we can derive the following conclusions:

- P2P technology is useful when some of the network links in DSLAM/CMTS switches or local offices are the bottleneck.
- If B_{1S} is the bottleneck, P2P sharing does not help because any peer sharing increases the downlink traffic of a DSLAM/CMTS switch. In fact, it will reduce the number of viewers that can be served.
- If B_{2N} is the bottleneck, P2P sharing among viewers in all communities of a local office helps to reduce the load on B_{2N}. However, if a service provider can apply other technologies to distribute video files from national offices to the local offices, P2P sharing may not be needed.
- If B_{1N} or B_{2S} is the bottleneck, P2P sharing within a community reduces the load on the north link of a DSLAM/CMTS switch and its local office. In this case, P2P sharing within a community helps to reduce the load on these congested links. However, P2P sharing across communities increases the possibility that B_{1N} or B_{2S} is a bottleneck. Therefore, P2P sharing across communities should not be used when B_{1N} or B_{2S} is the bottleneck. If a national video serving office is overloaded, an IPTV service provider can apply caching, load balancing, and other content distribution techniques to reduce the load on the national office. In this case, there is little or no benefit to apply P2P video sharing technology for viewers among national offices.

7. CONCLUDING REMARKS

The key challenges to provide P2P IPTV services are the quality of service, scalability, compression techniques and seamless integration of P2P streaming with proprietary IPTV platforms. In this paper, we focused on the scalability challenge. Scaling the networking infrastructure of an IPTV service to serve an increasing number of customers under a reasonable cost structure becomes a top priority to the IPTV service providers. P2P streaming could become one economical solution to the scalabilty problem. However, our study shows that P2P streaming may actually overload DSLAM / CMTS switches and therefore reduce the system capacity. The conditions under which P2P streaming could benefit IPTV service providers are discussed in the paper.

Based on the study, we have designed the MediaGrid P2P streaming algorithm. The algorithm intends to maximize the benefits of P2P sharing while minimizing possibility for network congestion. Due to the proprietary nature of the Microsoft^{TM} platform, tight integration presents implementation challenges.

For future work, to help us gain valuable insights and to validate our designs, we plan to deploy the MediaGrid system in real IPTV infrastructures. We also would like to apply several variations to the MediaGrid server and client algorithms for further optimization.

8. REFERENCES

[1] Simon Sheu, Kien A. Hua, Wallapak Tavanapong, *Chaining: A Generalized Batching Technique for Video-on-Demand Systems*, in Proc. of the IEEE Int'l Conf. On Multimedia Computing and System, Ottawa, Ontario, Canada, June 1997, pp. 110–117.

[2] Duc A. Tran, Kien A. Hua, Simon Sheu, *A New Caching Architecture for Efficient Video-on-Demand Services on the Internet*, in IEEE Symposium on Applications and the Internet (SAINT 2003), 2003.

[3] Duc A. Tran, Kien A. Hua, Tai T. Do, *A Peer-to-Peer Architecture for Media Streaming*, in IEEE Journal on Selected Areas in Communication, Special Issue on Advances in Overlay Network, 2003.

[4] Yang Guo, Kyoungwon Suh, Jim Kurose, Don Towsley *P2Cast: P2P Patching Scheme for VoD Service*, in WWW 12th, Budapest, Hungary, 2003.

[5] Stefan Saroiu, P. Krishna Gummadi, and Steven D. Gribble, *A measurement study of peer-to-peer file sharing systems*, in Proc. of ACM/SPIE on Multimedia Computing and Networking (MMCN'02), San Jose, CA, USA, January 2002.

[6] Eveline Velos, Virgilio Almeida,Wagner Meira, Azer Bestavros, Shudong Jin, *A Hierarchical Characterization of a Live Streaming Media Workload*, in IEEE IMW'02, 2002, pp. 117-130.

[7] Kien A. Hua, Mounir A. Tantaoui, *Cost Effective and Scalable Video Streaming Techniques*, in Borko Furht, Oge Marques (eds.): Handbook of Video Databases, CRC press, 2002.

[8] Yang-Hua Chu, Sanjay G. Rao, and Hui Zang, *A Case for End System Multicast*, in Proc. of ACM SIGMETRICS 2000, pp. 1-12.

[9] Yang Guo, Kyoungwon Suh, Jim Kurose, and Don Towsley, *A Peer-to-Peer On-Demand Streaming Service and Its Performance Evaluation*, in Proc. of IEEE Int. Conf. on Multimedia Expo (ICME'03), 2003.

[10] H. Deshpande, M. Bawa and H. Garcia-Molina, *Streaming Live Media over a Peer-to-Peer Network*, Stanford database group technical report (2001-20), Aug. 2001.

[11] S. Banerjee, Bobby Bhattacharjee, and C. Kommareddy, *Scalable application layer multicast*, in Proc. Of ACM SIGCOMM 2002, Pittsburgh, PA, 2002, pp. 205-217.

[12] J. Jannotti, D. Gifford, K. Johnson, M. Kaashoek, and J. O'Toole, *Overcast: Reliable multicasting with an overlay network*, in Proc. of the Fourth Symposium on Operating Systems Design and Implementation, 2000, pp. 197-212.

[13] Christos Gkantsidis and Pablo Rodriguez. Network Coding for Large Scale Content Distribution. In Infocom 2005.

[14] Mayank Bawa, Hrishikesh Deshpande, Hector Garica-Molina, *Transience of Peers and Streaming Media*, in ACM SIGCOMM Computer Commuications Review, January, 2003, vol. 33, pp. 107-112.

[15] Anwar Al Hamra, Ernst W. Biersack, Guillaume Urvoy-Keller, *A Pull-Based Approach for a VoD Service in P2P Networks*, HSNMC 2004, pp. 995-1006.

[16] *Swarmcast - OpenP2P - http://swarmcast.net/*

[17] *Kontiki - www.kontiki.com*

[18] *vSkype - www.vskype.com*

[19] M. Hefeeda and A. Habib and B. Bhargava, *Cost-profit analysis of a peer-to-peer media streaming architecture*, Technical report, CERIAS TR 2002-37, Purdue University, June 2003, http://citeseer.ist.psu.edu/article/hefeeda02costprofit.html

[20] *http://www.veritest.com/clients/reports/microsoft/ms_media_services.pdf*