A Simple and Robust P2P Scheme for VoD in a Resource Rich Walled Garden Network

Ayaskant Rath†, Peter Kubat*, Yong Liu‡, Shivendra S. Panwar‡,

Keith W. Ross‡, Rina R.Schneur*, Donald E. Smith*

†ARath01@students.poly.edu, ‡{YongLiu, Panwar, Ross}@poly.edu, *{Peter.Kubat, Rina.Schneur, DSmith}@verizon.com

†‡Polytechnic Institute of New York University, Brooklyn, NY, 11201, USA

*Verizon Network and Technology, Waltham, MA, 02451, USA

Abstract

Recent Deployments of Fiber-to-the-Premises (FTTP) networks, with their high bandwidth potential, have enabled to deliver a variety of new multi-media services to a customers home. In addition to broadcast TV, traditionally delivered by coax or fiber, new high bandwidth Internet connections are now available through such deployments. One of the very popular services is Video-on-Demand (VoD), which can bring standard or high definition video streams directly to the TV set. However, VoD does not scale well by itself, as each VoD stream traverses the transport network separately making its delivery rather expensive. In this article, we investigate an alternative delivery of VoD services. Specifically, we propose to deploy a peer-to-peer (P2P) like protocol in a restricted local environment, where the peers are connected via a 'private' high bandwidth network, and peer storage is fully controlled by the P2P manager. This so called 'walled garden' scenario has been simulated in great detail to get quantitative system performance measures, illustrate the feasibility and show the benefits of the approach.

I. Introduction

VoD services, where customers get to choose the video(s) they want to watch from a catalog, have gained tremendous popularity in recent years. A better VoD service is one which has a larger catalog, serves all videos in the catalog equally promptly and allows the subscriber to start watching the video as soon as they place the order and continue watching without interruptions. Thus, VoD services provide customers the flexibility to choose and pay for exactly what they want to watch. In most of today's systems, one VoD delivery stream uses one media streamer at the server, and consumes high bandwidth to transport the video all the way from the server to the subscriber's TV. Such systems lack scalability - as the number of subscribers increases, so must the corresponding serving and transport facilities - and both expansions could be very expensive. To avoid transport network expansion, one could deploy smaller, satellite VoD servers closer to the subscriber locations [1]. The satellite servers choose videos to store depending on user behavior in the serving locality. However such solutions still have to deal with replication of server hardware (and its corresponding storage) which is both expensive and difficult to manage optimally. This has led to the idea of using P2P solutions for VoD services. Instead of every user downloading a file from a single source, P2P schemes propose sharing of the load on the source by the users or peers. Such schemes have been successfully deployed in applications such as BitTorrent[2], SopCast[3] and have proved their efficiency in both load reduction on source server and scalability.

Using P2P solutions for VoD Services is a field of interest for many researchers. Comparatively lower number of peers concurrently downloading the same video makes VoD more challenging than streaming of live videos. In general, a P2P VoD service scheme uses a small amount of cache contributed by every peer along with the upload bandwidth available at each peer to be able to serve part of the demand from the system. There have been efforts to optimally use the available resources at the peers in order to achieve the best performance [4], [5], [6]. However, most of these efforts concentrate on how the small amount of cache available at peers can be used to the best of its potential; how the chunks from a video should be replicated; or how multiple source peers should be optimally chosen in order to use the available small upload bandwidths at peers most efficiently. There have also been strategies proposing pushing of content expected to be in high demand in the future to the peers at a time when there is low traffic on the network [7]. Thus, with time, the P2P schemes proposed to be used for VoD services have become more and more complicated to be able to achieve better efficiency.

Largely due to the impact of Fiber-to-the-Premise (FTTP) networks, today's VoD subscribers might have much higher bandwidths (both download and upload) available. Moreover, advances in digital storage media, may provide an inexpensive and substantial storage which can be easily engineered into the Set Top Box (STB). Thus, with STBs coming with hundreds of GBs of storage, the amount of cache each peer can contribute is now higher. As a result, instead of using the best of the P2P schemes available today, it has become essential to step back and re-examine the simpler techniques.

In this article, we propose a simple, but highly robust P2P scheme for VoD services in a resource rich environment. By 'resource rich', we mean a network with high upload and download bandwidths, as well

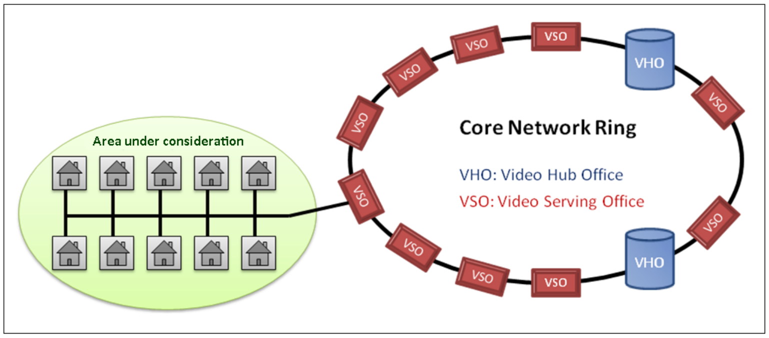

Fig. 1. Simplified schema of the Network Architecture

as large cache sizes, available to peers. The network is called a 'walled garden' network, if all caches at all peers are centrally managed and controlled and the up/down bandwidth is not being shared with third parties. We then move on to simulate the proposed scheme on a close to real world scenario. The results are very encouraging - bandwidth savings at the server of more than 95% can be expected.

The rest of the article is organized as follows. We start with describing the network used for the proposed scheme. We then describe the scheme in detail. Following this, the catalogs used in the simulation and the demand arrival technique used is discussed. This follows the details of the simulation set up followed by the results and analyses at the end.

II. The VoD Transport Network

Before looking at the proposed P2P scheme, it is important to understand the process of delivery of a VoD stream. We focus on the parts of the network that are significant for the VoD transport. Note that, in principle, the same network, or part of it may also be used to carry data and voice traffic, although these services end on different gateways.

We describe a typical regional scenario using FTTP access, shown in Figure 1. Video originates from servers in Video Head Office (VHO) which store all the videos listed in the Catalog. In a traditional server-client model, the VHO serves all the demands placed by the VoD customers assigned to it. At the other end, the subscriber's home is connected to the local central office, also called Video Service Office (VSO), via passive optical network (PON). Each VSO serves a group of customers in a certain locality. All the video data, being fed to the customers to serve their demands, comes from the VHO through the metro core ring to the VSO and then via PON to the customer's STB [8].

When a customer places a demand for a video via the VoD service, the video is downloaded to the disk space partition on the STB that is completely controlled by the service provider. Whether the customer is given the right to transfer the video to his part of the hard disk is out of the scope of this article and depends on the copyright agreements pertaining to the video. How many times the customer is allowed to watch the video is a similar issue.

When a customer requests a video, a space in his cache is immediately reserved for the entire video. If not enough space is available in the cache, the oldest video in the cache must be deleted first. But, in the (rare) case, when the downloading of the oldest video is still in progress, then the new request is denied.

III. The P2P VoD Scheme

The proposed P2P scheme aims to reduce the load on the VHO and the traffic on the core network ring by trying to make peers connected to the same VSO serve most of each others' demands. Note that from network traffic point of view, this, in effect, will work the same as having a high bandwidth video server in VSO. In the P2P scenario, however, the storage and hight bandwidth in the VSO video server is virtually replaced by a (much smaller amount of storage) cache in the many STBs. The following assumptions are made for simplicity.

- All peers under the VSO in consideration have equal and dedicated upload bandwidths for the VoD service.
- All peers have equal cache size. The cache at a peer, as explained above, is the disk space in the STB which is centrally controlled.

All rate measurements are made in a unit that we call Standard Download Rate (SDR). This unit can be converted to any other standard unit according to requirements. For example, 1 SDR can be thought of as 2Mbps or 3Mbps.

All uploads and downloads (for the VoD orders) in the proposed scheme take place in integer SDR units. Thus, any order placed is always served at a minimum rate of 1 SDR. Also, in the proposed scheme, download of a video starts as soon as the peer places the order. This implies that if the video play rate of the ordered video is lower than 1 SDR, then the user can start watching the video as soon as they place the order and continue watching without any interruption. When a peer orders a video, the entire video is downloaded whether or not the peer chooses to watch it.

Every demand is always served by a single download stream. In other words, there is a single source for every downloading video at any point of time. However, the source and the rate of a download stream may change several times during the course of the download.

Any peer who is serving at least one demand always uses all its upload bandwidth. More specifically, if a peer with upload bandwidth u_0 SDR is serving κ orders ($u_0 \geq \kappa$), then the upload rate for the first order is $(u_0 - \kappa + 1)$ SDR and that for the remaining $\kappa - 1$ orders is 1 SDR each.

A peer cannot order a video only if the total size of videos being downloaded at the time plus the size of the video the peer intends to order now is larger than the cache size. In other words, a peer cannot order too many videos simultaneously, if the total size of the ordered videos is more than the total cache size.

When a peer orders a video, space equal to the size of the video is reserved in the cache. If there isn't sufficient space, then one of the fully downloaded videos sitting in the cache is erased. Of all the fully downloaded videos, the one that was ordered earliest is selected to be erased. The situation described above, where a peer is not allowed to place an order arises when there isn't enough space to reserve for the video being ordered and there is no fully downloaded video in the cache. After the space reservation is done, a source search is triggered to find a potential uploader.

A peer with upload bandwidth u_0 SDR is a potential source for an order if

1) it has the complete file of the requested video in its cache; and
2) it is already serving less than u_0 orders.

The first condition checks for availability of content at the peer and the second checks availability of upload bandwidth. If such a peer is found as a result of a source search, it is chosen to serve the demand. If the chosen peer uploader is not already serving any demand, then it serves the demand using up all its upload bandwidth. On the other hand, if the chosen peer uploader is already serving a demand at a rate higher than 1 SDR, then that particular upload rate is reduced by 1 SDR and the peer starts to serve the new demand at the rate of 1 SDR.

If no potential peer source is found in a source search, the demand is served by the VHO. Every demand served by the VHO is served at the rate of 1 SDR. There is no upper limit to the number of orders that the VHO can serve. During the course of a download of a video from the VHO, if and when a peer capable of serving the particular demand appears, the upload is switched from the VHO to the peer.

The source of a download stream may change due to the following:

1) The peer, who was the source, erased the video. As a result, a new source search is triggered.
2) The VHO was the source, but now a potential peer uploader has appeared. A potential peer uploader may appear because of one of the following:

a) A peer just finished downloading the same video, can sustain one more upload, and hence become the source.
b) A peer who has the same video just stopped an upload service, and hence can now become the source.

As described above, the rate of a download stream may change several times during the download. The reason for such a change can be one of the following:

1) The source has changed, and hence the rate at which the new source can serve can be different from the previous rate.
2) The peer, who is the source, is now serving another demand, thus reducing the rate by 1 SDR.
3) The peer, who is the source, has just stopped another upload, thus increasing the rate by 1 or more SDR.

The proposed scheme ensures an upper bound on the time taken by a peer to download a video when an order is placed, depending on the size of the video. Unlike many other access networks, the 'resource rich' nature of the network, which implies that there is a lot of bandwidth available, makes this simple and robust scheme give very good performance. The high upload bandwidths at peers enable a single download stream to satisfy a demand. Also, ample peer cache helps the peers to serve more demands than otherwise possible and avoids the necessity to break videos into chunks to store them at various locations. This avoids the need of much more complicated management of chunks of videos.

IV. Catalog for Simulation

For the simulation to reflect a scenario very close to reality, it is important that the Catalog of available videos and its updating is well modeled. The Catalog updating scheme greatly affects the performance of any P2P service system. Just to understand the importance of a Catalog updating scheme, we may look at two extreme unrealistic scenarios. The first may be one where the Catalog remains the same for months together and the second may be one where the catalog is totally flushed and refilled with new videos every few hours. In the first case, if we assume steady demand for every video, the peers, added together, soon cache all the videos in the catalog, and when steady state is reached it may be possible to serve almost all demands just using the peers, thus making the VHO almost free. On the other hand, for the second case, the peer cache will never have current videos in the catalog and this will result in almost all demand being directed to the VHO all the time!

In our simulation set up, we assume the popularity distribution of videos in the catalog at any point of time to follow a Zipf Law [9] with a fixed parameter. This implies that throughout the duration of the simulation, the popularity of a particular video simply depends on its popularity rank in the catalog at that time. The catalog size, which is the number of videos in the catalog, is always fixed. The Catalog is updated every time there is a new video released. Such an event involves the addition of new videos released to the Catalog, removal of an equal number of the most unpopular videos from the Catalog, and a change of ranks of videos in the Catalog.

For our simulation set up, we consider the following scenario:

- There are two different Catalogs - a Children's Catalog; and an Adults' Catalog. Children's Catalog contains videos for children and Adults' Catalog contains videos for adults.
- Videos in the Children's Catalog are of shorter duration (and hence smaller size) than those in the Adults' Catalog.
- All videos in a catalog are of the same size.
- Updating of a catalog is an event that occurs when a new video is released and hence added to the catalog.
- Every new release takes one of the top ranks in a catalog, hence pushing all videos below it further down.
- As a result of new releases being added to a catalog, an equal number of videos at the bottom of the catalog are removed.
- The catalogs are updated every midnight. In other words, new releases occur every midnight.
- The number of new releases is the same for every update except for the one occurring at midnight of Friday into Saturday, when there are a slightly higher number of new releases. (The exact numbers used are described later)

It is necessary to have two different catalogs because the distribution of demand is very different for the two kinds of videos, in particular, as a function of the time of the day. In addition, as mentioned above, children's videos are usually shorter than adults' videos.

V. Demand Arrivals

In the simulated environment, the following conditions are assumed for the arrivals of demands:

1) All peers who are part of the network, place orders.

2) When a peer places an order, the video being ordered is chosen by the popularity distribution of the videos in the catalog. Thus, the probability of an order being for a particular video is proportional to the popularity of the video in the catalog, which in turn is dictated by the underlying Zipf law.
3) A peer never orders a video that it already has in its cache (which implies that the peer had recently ordered this video). In other words, a peer sees only those videos of the catalog that it doesn't have in its cache. The probabilities are scaled up accordingly.
4) The demands arrive following a Poisson Process. The average demand arrival rate depends on the time of day. For example, demands arrive at a higher rate in the evenings compared to mornings.
5) The simulation uses a basic average demand arrival rate λ (called the normal arrival rate) and the actual rate at any time is λ times a function of time of the day.

VI. Simulation Set Up

The simulation scenario consists of N peers. The number of videos at any point of time in the Children's Catalog is M_c and that in the Adults' Catalog is M_a. The number of new releases every day (at midnight), except Saturday, in each catalog is ν and that on Saturday is ν'. Thus, the total number of new releases in each catalog every week is $(6\nu + \nu')$. The popularity of videos in each catalog follows a Zipf Distribution curve with parameter k as usually used for videos in VoD services [10]. Thus, the popularity of a video whose rank in its catalog is m, is $p_c(m) = \frac{m^{-(1+k)}}{\sum_{i=0}^{M_c} i^{-(1+k)}}$ or $p_a(m) = \frac{m^{-(1+k)}}{\sum_{i=0}^{M_a} i^{-(1+k)}}$, respectively. At any midnight, each of the newly released videos takes one of top μ_c and μ_a ranks in the Children's and the Adults' Catalogs, respectively. Time in the simulation is counted in time slots, equivalent to minutes in the real world. An hour consists of 60 time slots, a day consists of 24 hours, and a week consists of 7 days. The simulation runs for a period of W weeks.

The length of videos is measured in chunks. One chunk of video is the amount of video that can be downloaded in one time slot at the rate of 1SDR. All videos in each catalog are of equal length. The length of videos in the Children's Catalog is τ_c and the length of videos in the Adults' Catalog is τ_a. The cache size of every peer in the network is C. The upload bandwidth of every peer in the network is u.

The normal arrival rate for the simulation is λ. However, the actual mean demand at any point of time is $\lambda\eta(h)$, where $\eta(h)$ is a factor that is a function of the hour of day h. The probability that order is for a Children's video is $d_c(h)$ and that to be for an Adults' video is $d_a(h)$. At any point of time, $d_c(h) + d_a(h) = 1$.

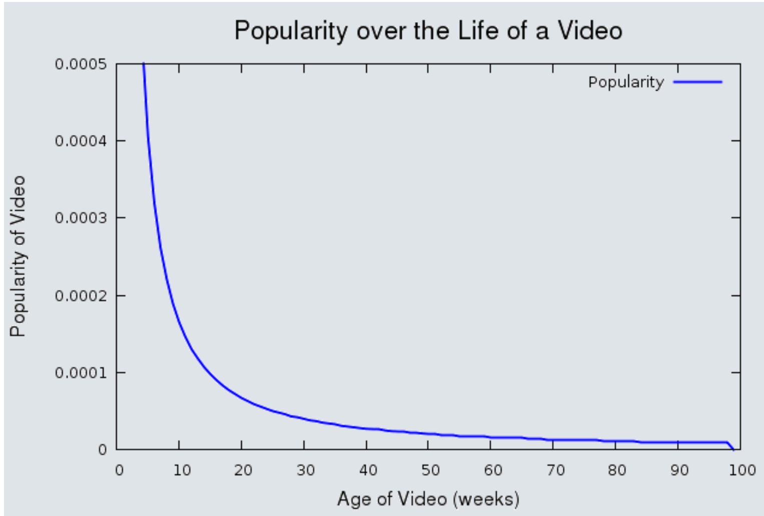

Fig. 2. Popularity of videos in catalog with their ranks

A. Basic Parameter Values

The values of the above parameters set for the simulation are given below:

- $N = 4000$
- $M_c = M_a = 3000$
- $\nu = 4$
- $\nu' = 6$
- $\mu_c = \mu_a = 30$
- $W = 8$
- $\tau_c = 30$ chunks
- $\tau_a = 60$ chunks
- $C = 900$ chunks
- $u = 2$ SDR

B. Popularity of Videos

The Zipf parameter used for the popularity of videos in both the catalogs is $k = 0.3$. Since every newly released video pushes everything in the catalog under it further down, a video just released into the Children's catalog for example, stays in the catalog for approximately $\frac{M_c}{6\nu+\nu'}$ weeks. The popularity of such a video goes down the Zipf curve day after day. Figure 2 shows the popularity of a video over its life time for the parameters used here.

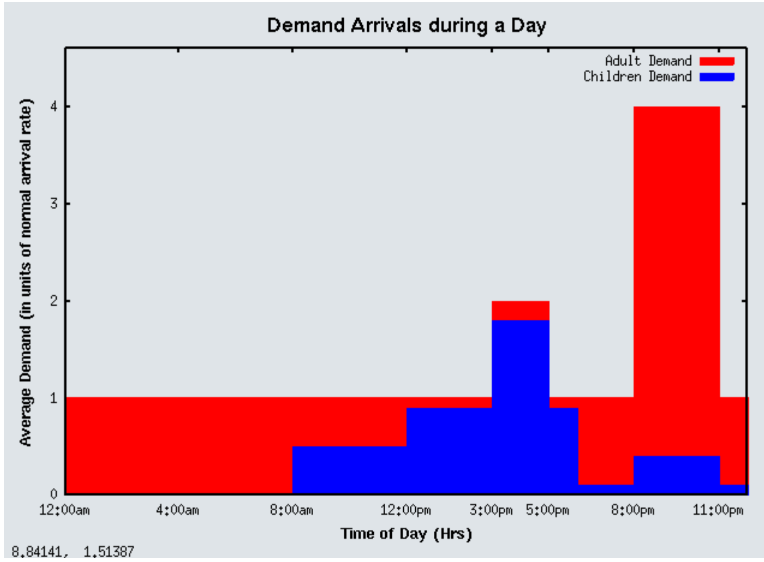

Fig. 3. Demand distribution for the two catalogs used

C. Demand Arrival

The normal demand arrival rate is set to $\lambda = 1.33$ orders per time slot, for all the peers added together. Apart from this, the function $\eta(h)$ is set as

$$\eta(h) = \begin{cases} 2 & \text{if } 15 \leq h < 17 \\ 4 & \text{if } 20 \leq h < 23 \\ 1 & \text{otherwise} \end{cases}$$

This implies that a peer orders approximately five videos every week. The function $d_c(h)$ is set as

$$d_c(h) = \begin{cases} 0.0 & \text{if } h < 8 \\ 0.5 & \text{if } 8 \leq h < 12 \\ 0.9 & \text{if } 12 \leq h < 18 \\ 0.1 & \text{if } h \geq 18 \end{cases}$$

As mentioned before, at any point of time,

$$d_a(h) = 1 - d_c(h)$$

Figure 3 shows how the average total demand arrival rate varies during the day (the envelope), and the portion of the total demand from each of the two catalogs. The variation is kept identical for every day in a week. The parameters are set taking into account the real world scenario, where most children watch

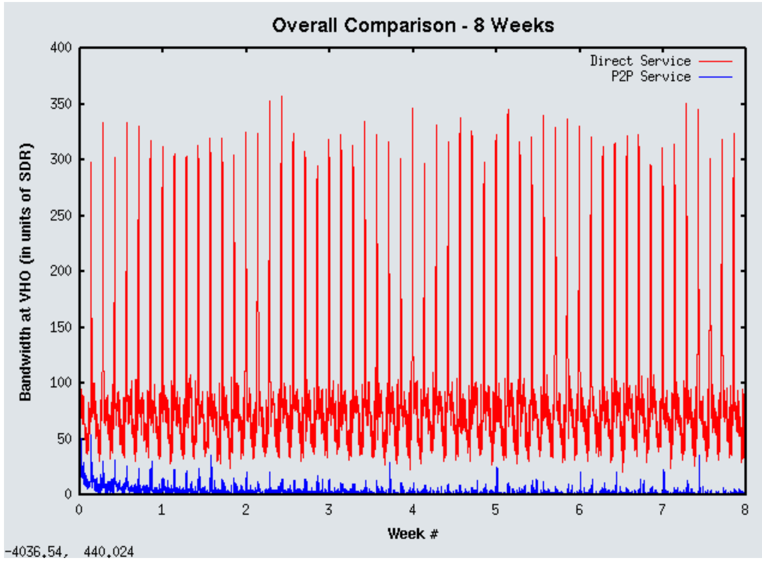

Fig. 4. Overall comparison of the VHO bandwidth usage in the two schemes

their videos during afternoon hours and adults during the evening hours.

VII. Analysis of Results

The first and most important result of the simulation is the comparison of the VHO bandwidth usage in a direct server download VoD service to that in the proposed P2P VoD service. Figure 4 shows this comparison during $W = 8$ weeks of the simulation period. The average VHO Bandwidth usage in a direct server download VoD service is found to be 175.8 SDR and that in the proposed P2P Scheme is a mere 4.16 SDR. The simple and robust P2P scheme is able to reduce the load on the VHO by more than 95%. Note that although there are a few peaks in VHO bandwidth usage in the P2P scheme, these peaks are lower than the average VHO bandwidth used in the direct download service. Also, the peak VHO bandwidth usage in direct download service goes as high as 350 SDR during the peak viewing hours.

The VHO usage in a direct download service actually gives us an idea about the actual demand. Approximating the VHO bandwidth usage in direct download service to the total demand in the proposed P2P scheme (due to identical VoD request rates) lets us conclude that in the proposed P2P scheme, close to 95% of the demand is handled by the peers. In other words, the core ring network only sees 5% of the demand.

Apart from reducing the average bandwidth usage at the VHO, reducing the peak bandwidth of the server is potentially a important cost-cutting measure. Reducing the peak VHO bandwidth usage by more than 90% can result in huge infrastructure savings. Figure 5 show the same results magnified to a Saturday.

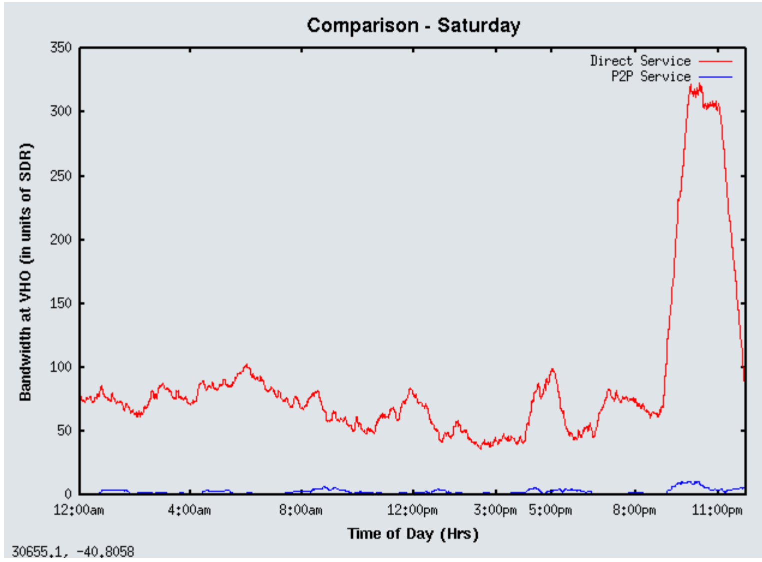

Fig. 5. Comparison of the VHO bandwidth usage in the two schemes during a Saturday

It is clear that even a P2P scheme as simple as the one proposed can achieve great savings even with a reasonable amount of change in the catalog.

Note that new releases occur at midnight. From the plot, it is clear that even though there is an addition of 6 new videos in each catalog, which take ranks among the top 30, there is no spike in the blue curve, which is an indicator of VHO utilization. Apart from this, even in the afternoon and the evening hours, when there is a spike in the demand, which is evident in the red direct service curve, the corresponding spikes in the blue curve are negligible. The rate still stays below 25 SDR!

Another aim of the simulation is to analyze the tradeoff between the cache size at the peers and the bandwidth savings at the VHO. It is natural that more VHO bandwidth savings can be achieved by increasing the peer cache. Figure 6 shows the decreasing average VHO bandwidth usage with increasing size of the peer cache. When the cache size is increased from 90 chunks per peer to 900 chunks per peer, the average bandwidth used at the VHO is reduced to almost a third of its value. However, further increases in the cache size do not help as much. These results give us an idea about how much cache in the STB should be reserved for central control as one would like to obtain the maximum benefit for the minimum cache on the STBs.

VIII. Conclusions

Due to the complex nature of the system, and the deployment of the P2P scheme on it, it is fairly difficult to obtain analytical quantitative measures of performance. Hence, to obtain quantitative performance statistics, the system was simulated in all details.

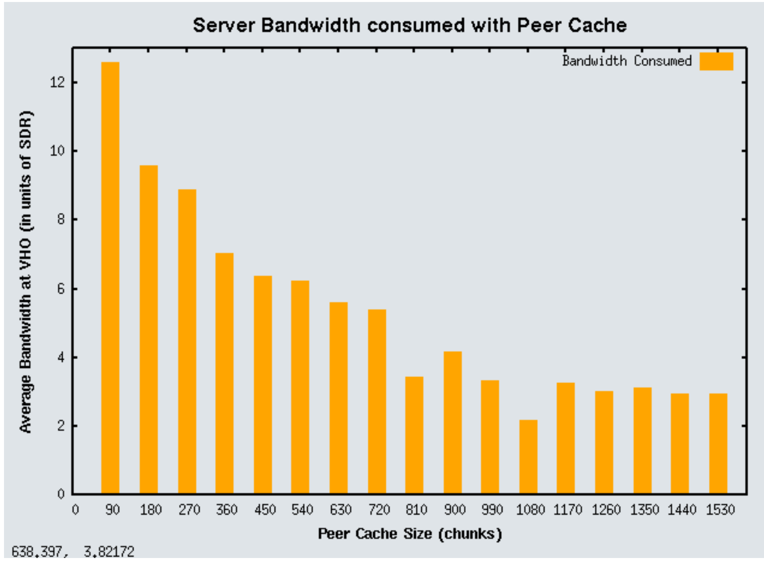

Fig. 6. Average VHO Bandwidth usage with increasing Cache at peers

Based on our comprehensive simulations, we conclude that deployment of a simple and robust P2P distribution protocol for VoD delivery on the FTTP network can bring down the traffic on the metro core rings by as much as 95%. Moreover, it reduces the traffic load on the VoD servers. Such traffic reduction may delay future network infrastructure and server upgrade and expansion, thus significantly reducing capital and operations spending. We have shown that such benefits can be obtained even with a very small amount of peer cache (typically part of the disk space on STB).

Also, it is evident from the simulation results that such a system can sustain a sudden and huge rise of demand. Sharp surges of local demand do not affect the video servers in the VHO.

With P2P properly implemented, VoD delivery in a private network setting scales well; there is almost no cost associated with adding new VSOs to the system, or handling significant increases in the demand rate.

The P2P efficiency can be further improved by allowing multiple sources for every download and by allowing a peer to start uploading a video, even if they have not downloaded it completely; however such improvements will also need more complex data management.

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