When is P2P Technology Beneficial for IPTV Services?

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Abstract- This paper studies the conditions under which peer-to-peer (P2P) technology may be beneficial in providing IPTV ser-vices over typical network architectures. It has two major contributions. First, we contrast two network models used to study the performance of such a system: a commonly used logical “Internet as a cloud” model and a “physical” model that reflects the characteristics of the underlying network. Specifically, we show that the cloud model overlooks important architectural aspects of the network and may drastically overstate the benefits of P2P technology by a factor of 3 or more. Second, we provide a cost-benefit analysis of P2P video content delivery focusing on the profit trade-os for different pricing/incentive models rather than purely on capacity maximization. In particular, we find that under high volume of video demand, a P2P built-in incentive model per-forms better than any other model for both high-definition and standard-definition media, while the usage-based model generally generates more profits when the request rate is low. The flat-reward model generally falls in-between the usage-based model and the built-in model in terms of profitability.

Keywords- IPTV, P2P streaming, content distribution network, FTTN, Video-on-Demand.

I. INTRODUCTION

Internet protocol TV (IPTV) promises to viewers an innovative set of choices and control over their TV content. Two major U.S. telecommunication companies, AT&T and Verizon, have invested significantly to replace the copper lines in their networks with fiber optic cables for delivering many IPTV channels to residential customers.

A viewer can receive IPTV videos in good quality if the

Available bandwidth satisfies the need of video encoding rate for the target resolution and frame rate. To provide sufficient bandwidth for IPTV services, Internet service providers use high speed xDSL or cable networks to deliver video con-tent to viewers’ set-top boxes. As an example, AT&T Light-Speed is using Fiber-to-the-Neighborhood (FTTN) Networks. Its architecture consists of a small number of national super head-ends (SHE) and a large number of local video hub offices (VHO). The super head-ends serve as the national content aggregation points for broadcast and video on demand encoding. The local video hub offices provide aggregation and storage of local content. Each video hub office serves as a Video-On-Demand (VOD) library and distributes video content through local access switches to the customers. We refer to this network hierarchy as the “physical” model throughout the paper. FTTN networks can provide 20-25Mbps bandwidth to each household, which is typically enough to support several high quality TV streams as well as high speed Internet and Voice over IP (VoIP) services.

A significant problem in providing IPTV services is its high deployment and maintenance cost. In addition, the capacity of the video servers can quickly become a bottleneck. One solution to alleviate the load on servers is to use peer-to-peer (P2P) systems like Skype [15] or Kontiki [10]. While early P2P systems were mostly used for file downloading, recently there have been several efforts on using the peer-to-peer approach to support live streaming [16][17][5][2][3][11] and VOD streaming[14][7][13][6]. Existing research studies that evaluate the benefits of P2P video content delivery typically do not consider the constraints of the underlying service infrastructure (e.g., [12][18]). Rather, they view the network as a “cloud”. Researchers, however, are increasingly aware of the need to reduce cross-ISP P2P track, while maintaining satisfactory P2P performance [4]. In this paper, we reveal the deficiency of this cloud model and investigate when P2P streaming can be beneficial in an IPTV environment. As we will see, P2P video sharing can be harmful under certain network conditions.

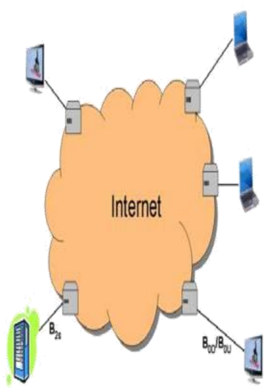
Another challenge for P2P streaming in an IPTV environment is the pricing strategy. Most broadband ISPs today charge a flat fee for providing bandwidth. Usage-based pricing has emerged in some markets but even in those cases it is limited to volume-based pricing. Among the limited early work on pricing strategies for P2P, Adler, et al. [1] pro-vided a comprehensive model applicable to a variety of P2P resource economies. Implementation of peer selection algorithms in realistic networking models like the IPTV environment was not addressed. Hefeeda et al. presented a cost- profit analysis of a P2P streaming service for heterogeneous peers with limited capacity [8]. The analysis shows that the service provider can achieve more profit by providing the appropriate incentives for participating peers. However, their analysis did not consider the bandwidth constraints of the underlying infrastructure and hence cannot be easily extended to our IPTV environment.

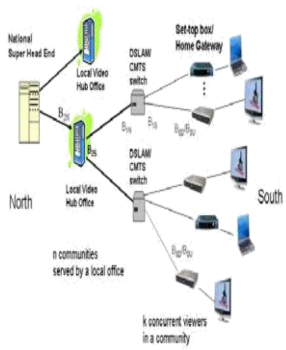
We make the following contribution in this paper:

- We compare two network models (the "cloud" model and the "physical" model) and show that the cloud model can dramatically overestimate P2P benefits by a factor of 3 or more.

- We couple three P2P pricing models (flat-fee, usage-based, and built-in) with a "physical" model and study their tradeoff s from a profit perspective.

The rest of the paper is organized as follows. We describe the physical network model and constraints for the IPTV system in section 2. Section 2.3 provides the insights as to why a more accurate physical network model is necessary to realize a profitable IPTV system. Three diff erent pricing models are analyzed and simulated in section 3. Section 4 provides a conclusion and potential future work.





II. NETWORK MODELS

This section contrasts two network models that can be used in studying the performance of P2P video content de-livery.

2.1 Cloud Model

Research in P2P streaming typically considers Internet at a logical level. it represents the Internet at large as an abstract cloud and only considers the capacity of the content server and the characteristics of the access links to related hosts. We refer this view of the Internet as the "cloud model" as shown in Figure 1.

2.2 Physical Model

In contrast to the cloud model, the physical model considers the network architecture and bandwidth constraints of the underlying links and network devices. In [9], we de-scribed and analyzed the physical model of FTTN access networks for IPTV services. The model and analysis can also be applied to xDSL or Cable connections.

As shown in Figure 2, video streaming servers are organized in two levels - a local video hub office (VHO), which consists of a cluster of streaming servers or proxies to serve viewers directly, and national super head end (SHE) offices, which can distribute videos to local serving offices based on existing policies or on demand. We concentrate on video on demand (VOD) in this paper. Each local VHO office (often referred to as "local office" below) connects to a set of access switches such as xDSL, FTTN or Cable switches through optical fiber cables. Each switch connects a community of IPTV service customers through twisted-pair copper wires, fibers or coaxial cables. A community consists of all homes which are connected to the same access (xDSL or Cable) switch. A local VHO also includes a service router to connect to a national SHE office. These uplinks (or "north-bound links") of local offices are implemented over high-speed optical fiber networks.

The following parameters are used throughout the paper:

- B0D: Download bandwidth into a home.
- B0U : Upload bandwidth out of a home.
- B1S: Total capacity of south-bound links (downlinks) of a local access switch.
- B1N : Capacity of the north-bound link (uplink) of an access switch determined by the total bandwidth of north-bound fibers from a switch to a local VHO and the switching capacity of the service router in the VHO.
- B2S: Maximum throughput in a local VHO deter-mined by capacities of service routers, optical network cables and/or streaming servers in the VHO.
- u: Average streaming bit rate for a video.
- N: Maximum number of concurrent viewers supported by a local VHO.

2.3 Network Constraints under Physical Model

In a physical network environment, all P2P upload traffic has to traverse through the access switches and service routers that connect the peers. As a result, P2P streaming will increase the load of access switches, local offices and national offices.

Compared with the conventional IPTV services, P2P sharing within a community may not be beneficial if the south-bound link bandwidth of an access switch is the bottleneck. However, P2P sharing within a community decreases the load on the north-bound link of an access switch. Therefore, P2P sharing within a community will have the most benefit if the infrastructure bottleneck is on the north-bound link bandwidth of an access switch.

Similarly, P2P sharing among peers across communities increases the traffic on both the north-bound links and the south-bound links of access switches. If the network bottleneck is in either B1N or B1S, P2P sharing among peers in all communities creates more congestion for the switches and decreases the number of concurrent viewers which can be served by a local office. In this case, P2P sharing across communities is not beneficial for IPTV service providers. Also, if an IPTV service provider can apply content distribution network (CDN) technologies such as caching and replication to reduce the workload in SHE, the benefit of P2P sharing across communities in a VHO is very limited. The detailed analysis of network constraints for P2P IPTV services can be found .

III. NETWORK AT THE PHYSICAL LEVEL

A key insight of this paper is that using the "cloud model" for P2P streaming is over simplistic and misleading. More reliable results can be obtained by considering the network at the physical infrastructure level. To demonstrate our point, consider the following simple P2P algorithm. The content server receives a request for a video, identifies candidate peers with that video and spare upload capacity, and selects a random set among them to collectively serve the video. If not enough candidates are available to serve the video at its encoding rate, the server tries to serve the remaining portion itself, or denies the request if it cannot.

We used a slice of the infrastructure of Figure 2 corresponding to one local office with 20 communities and considered the situation where the content server in the local office distributes video content to the viewers in these communities. For the cloud model, we assume the same content server and viewers are connected via the Internet cloud. We assume the same behavior for every node in the community: an idle user requests a stream with probability of 2% every time tick. A time tick occurs every minute. A peer may download only one stream at a time. There are 1000 video programs available for viewing. When a peer issues a request, it selects a program according to Zipf's popularity distribution. Each stream lasts 120 minutes and has a data rate of 6Mbps.1 Once downloaded, the program remains available at the peer for a period called the stream time-to-live (stream TTL) with a default value of 1000 minutes. A peer may be turned off and on by its user. An

operational peer is turned off with probability 0.1% on every time tick, and a non-operational peer is turned on with probability 0.5% on every tick. This means that on average every peer stays on five times longer than it stays off. We further assume that B1N = 0.622 G (OC-12), and B2S = 10 G. Each data point in the graphs throughout the paper is obtained by running the simulation program over 5000 time clicks and taking the average over the last 2500 time ticks (when the system reached a steady state in all the simulations).

The results for the cloud and physical models are shown in Figure 3. The figure also includes curves for the system that does not use P2P delivery under the physical model. Figure 3a shows the average number of concurrent viewers the system can support as the number of peers grows for fixed network and server capacities. The cloud model indicates that P2P delivery allows the system to serve more concurrent viewers and to scale to the growing number of viewers. However, the result is drastically diff erent when the limitations of the physical infrastructure are brought into the picture. In fact, the cloud model could overestimate the benefit by a factor of 2 when there are more than 800 peers in a community as shown in Figure 3a. Not only does the P2P system serve fewer users, it does not scale with a growing number of users and has only a slight capacity ad-vantage over the much simpler centralized delivery (which in fact turns to slight disadvantage for other parameter set-tings as seen in Figures 3b and 3c). The reason behind this drastic change is the limitations of B1N , the links between the local office and individual access switches. When P2P delivery occurs across diff erent communities, two of these links are traversed: one upstream from the serving peer to the local office, and the other downstream from the local office to the receiving peer. Overall, these links are more heavily utilized under P2P delivery and more requests are denied.

Now consider the number of concurrent viewers under varying capacity of the office-to-access-switch link (Figure 3b), when the community size is fixed at 500 viewers. The results for the cloud model are not ejected by this link since the model does not consider it. However, the physical model reveals an important trend: the centralized delivery becomes quickly bottlenecked at the server and stops responding to the growing bandwidth of the office-to-access-switch link. On the other hand, with P2P delivery, improvement in this link's capacity produces a roughly linear growth in the number of concurrent viewers served, at least within the band-width range studied.

IV. CONCLUSIONS

This paper studied the conditions under which P2P technology may be beneficial in providing IPTV services. We show that the cloud model may drastically overstate the benefits of P2P video content delivery. Thus, one must consider physical network infrastructure to obtain more reliable results. Finally, we provide a cost-benefit analysis for different pricing/incentive models. In summary, P2P may not be beneficial for IPTV services unless we employ properly

V. REFERENCES

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