# End-User IPTV Traffic Measurement of Residential Broadband Access Networks

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***Abstract*—Offering IPTV to broadband access subscribers is a key challenge as well as a prospective revenue source for ISPs. Despite of its growing interest, no comprehensive study has presented the traffic details of real-world commercial IPTV services yet. We have measured commercial IPTV traffic via four different residential broadband access networks, namely xDSL, Cable, FTTB, and FTTH. In this paper, we present traffic statistics and insight of the IPTV traffic impact onto these end-subscriber broadband accesses. We also present the mathematical formulas to describe traffic behavior and bandwidth demand in IPTV VoD services.**

***Keywords: IPTV, traffic measurement and analysis, passive measurements***

## I. INTRODUCTION

Telecommunication service providers (Telcos) around the world are introducing various bundled services [6] over broadband access networks in order to compete with cable companies and to generate new revenue. IPTV is envisioned as a key player in the upcoming IP convergence networks. The research community and industry have almost overcome technical issues of deploying IPTV service into the existing or redesigned infrastructures. However, the consequences of introducing IPTV traffic have not been thoroughly studied yet. We have measured commercial IPTV service traffic in four different types of residential broadband access networks, namely, xDSL, Cable, Fiber to The Building (FTTB), and Fiber to The Home (FTTH). The currently available commercial IPTV service in our reach is a Video-on-Demand (VoD) service by using set-top box (STB) which relies on two separate transmission techniques: Streaming and Download & Play (D&P).

In this paper, the IPTV service traffic using the D&P approach is our primary focus where it does not exactly coincide with the channel surfing and transmission modeling [5] in a real-time multicast environment. We present traffic statistics and insight of the IPTV traffic onto broadband access networks. We also analyze the traffic volume patterns in the client domain to characterize IPTV traffic and to construct the bottom-up fashion bandwidth demand approach.

The organization of the paper is follows. Section II presents the related work on real-world measurements of IPTV traffic and its traffic models. In Section III, we explain our measurement environments and IPTV traffic characteristics of the collected traces. Section IV presents the proposed formulas for IPTV VoD bandwidth demand analysis and simulation results. Concluding remarks and possible future work are given in Section V.

## II. RELATED WORK

To our knowledge, no comprehensive study has presented the traffic details of real-world commercial IPTV STB services. Yet, the traffic from similar IPTV services can provide a glimpse at IPTV traffic characteristics in general because it involves a heavy transmission of video streaming. According to ITU-T's definition of IPTV [7], the multimedia streaming over IP networks with the reasonable quality assurance can be interpreted as one of IPTV services. P2P IPTV service is an emerging application that attracts the viewers from the regions where a particular broadcasting channel, such as a sporting event, is unavailable. A large scale measurement study of P2P IPTV networks [2] presented the user behavior where the logics behind are similar to those of typical P2P overlay networks. Among its analysis categories, the paper showed the steady number of residing peers in the popular channels and the presence of significant upload traffic from the participating viewers. The churn rate and logical distribution of peer nodes are not much of concern in the upcoming IPTV STB environment. Silverston *et al.* [1, 3, 4] have measured the real-time traces of popular P2P IPTV services and presented its traffic characteristics. They found that there exists a clear grouping of heavy and light traffic, video and signaling packets, respectively. Interestingly, the quality of experience does not impact heavily by the network load at the time of measurement.

Others proposed mathematical modeling of IPTV traffic in order to estimate bandwidth demand in deployment [5, 8]. Their assumption was made on where a real-time live multicast with SD or HD quality is constructed regardless of the broadband access network type. The formulas describe the bandwidth demand trajectory while a steady-state bandwidth of each channel and occasional channel surfing traffic burst. However, the given modeling approaches may not be able to accurately describe the IPTV VoD services presented in this paper due to the absence of channel surfing traffic burst.

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TABLE I. LINK PERFORMANCE MEASUREMENTS OF THE SELECTED MONITORING LOCATIONS

| | xDSL | Cable | FTTB | FTTH |
|---|---|---|---|---|
| **Upload** | 415 Kbps | 2.5 Mbps | 93.5 Mbps | 94 Mbps |
| **Download** | 6.8 Mbps | 59.7 Mbps | 91.9 Mbps | 78.8 Mbps |
| **Ratio - up:down** | 1:16 | 1:23 | 1.01:1 | 1.2 : 1 |
| **Avg. RTT (range)** | 16.41 ms (15.27~18.93ms) | 9.70 ms (5.73~22.25ms) | 7.24 ms (6.68~50 ms) | 1.35 ms (1.10~2.40 ms) |

TABLE II. PACKET TRACE SUMMARY

| Transmission Type | via | Trace Volume (Mbytes) | # of Packets (K) | TCP (%) | # of Flows | Running Time (mins) | Transmission Time (mins) |
|---|---|---|---|---|---|---|---|
| D&P | xDSL | 792 | 877 | 99.9 | 324 | 46 | 20 |
| | Cable | 1,931 | 1,277 | 99.9 | 85 | 89 (2 episodes) | 43 |
| | FTTB | 810 | 878 | 99.9 | 48 | 42 | 14 |
| | FTTH | 833 | 885 | 99.9 | 140 | 42 | 13 |
| Streaming | xDSL | 531 | 573 | 99.0 | 393 | 46 | 46 |

## III. MEASUREMENT ANALYSIS

This section provides an overview of our measurement environments and characteristics summary. The empirical analysis results of the collected IPTV traces are presented as follows: throughput, packet distributions, and reordering analysis.

### *A. Measurement Environments*

We have subscribed to two commercial IPTV services, MegaTV [9] and HanaTV [10], provided by the two biggest Telcos in Korea. The number of IPTV subscribers in nation wide is over 150,000 and 500,000, respectively. Single program content is allocated with an instance of channel; consequently, both IPTV services offer more than 30,000 available channels. Due to the government regulation, they both provide the VoD services only as of 2007 although they are technically ready for live TV broadcast. To ensure SD quality video or above, they engage in D&P fashion which fulfills the buffer in advance while delaying the initial display time. Meanwhile, the streaming type IPTV solution by MegaTV is also offered with slightly lower quality.

STBs can be installed across the different locations regardless of the broadband access providers. The available residential broadband networks in our measurement are xDSL, Cable, FTTB, and FTTH. Table I illustrates the link performance statistics against the testing server at the national Internet quality monitoring agency (http://speed.nia.or.kr) prior to packet collection.

Fig. 1 shows the IPTV VoD deployment topology in the measurement environment [13]. It consists of the client, network provider, and content provider domains. The backbone network of network provider domain is QoS-enabled network while the access network (behind aggregation switch) is best effort network. In practice, the traffic from the regional pop (e.g., L3 switch) to the subscriber is delivered by unicast.

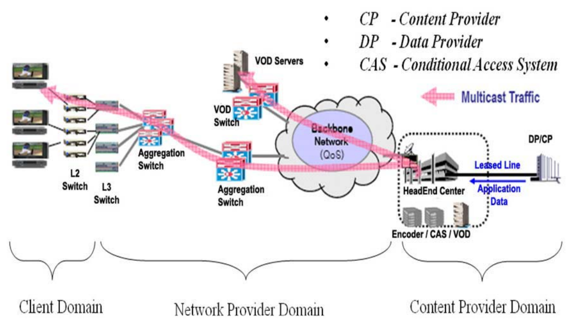


Figure 1. IPTV VoD deployment topology

### *B. Throughput via Broadband Access Networks*

The packet traces are collected while watching one or more episodes from the popular TV series, CSI Miami. We use the 100 Mbps copper network tap (full-duplex) to intercept the packets in and out of the STB. The PC with two interfaces running tcpdump stores the first 96 bytes of packet header. Table II shows the packet trace summary of each collection trial. The trace volumes reflect the file size of each video clip in transmission. All channel transmissions are established over TCP. No flashback or frame stoppage has been observed at the time of measurements. For the D&P service solution, we discovered that the actual packet transmission is completed in the early stage of channel viewing period. In other words, the transmission time is not equal to the total running time of the content. Depending on the subscribed access networks, the complete delivery time to STB varies from 13 to 20 minutes for a 40-minute episode.

Fig. 2 illustrates the traffic burst periods of each monitoring location. In (a), the throughputs in FTTH and FTTB show about 13 minutes long traffic burst period where they generate 10~11 Mbps constantly. Those in Cable and xDSL are 2/3 of the bandwidth allocated in FTTH. For xDSL, it almost reaches the maximum available download rate, 6.8 Mbps in Table I. In fact, the transmission time is inversely proportional to the maximum throughput that can reach on the fixed video file size.

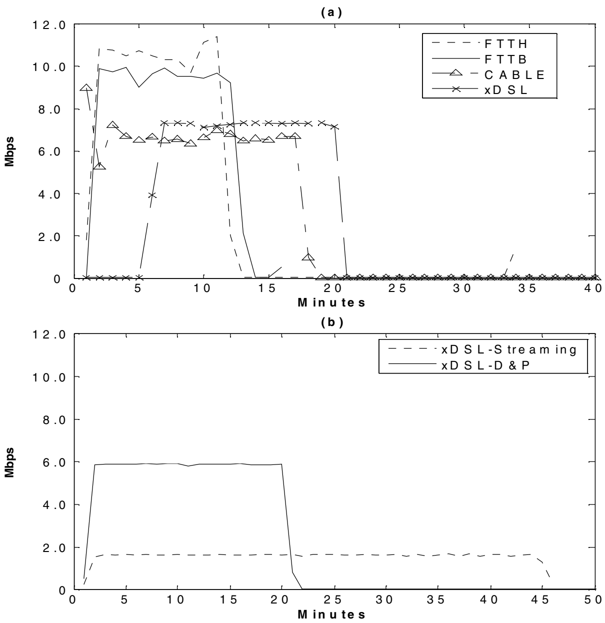


Figure 2. Total throughput via broadband access - (a) D&P; (b) D&P vs. Streaming via xDSL.

We observed a rather steady-state traffic delivery in streaming type IPTV service. Fig. 2 (b) presents a comparison between D&P and streaming IPTV services via xDSL. The D&P type completes its download with initial traffic bursts while the streaming type shows low yielding bandwidth through the entire running time. Because it delivers the content over a longer time period, the quality of streaming could be more overlapped with or vulnerable to other types of traffic burst in the residential line, such as Web surfing, P2P file sharing, and VoIP. These two concrete patterns in traffic delivery should be considered thoroughly when planning bandwidth demand and analyzing the impact on cross traffic.

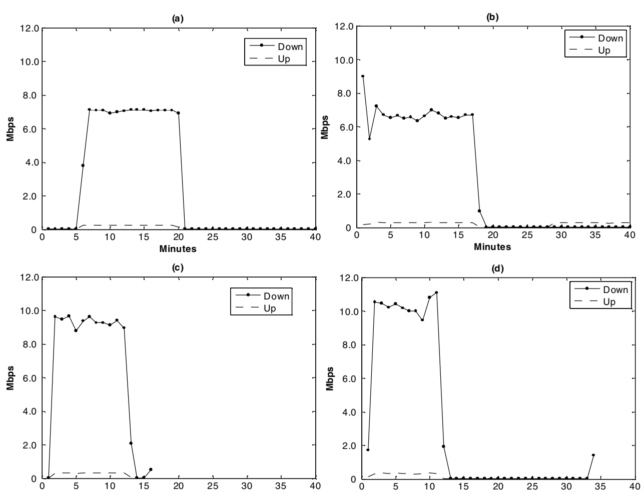


Figure 3. Total upload and download throughput for D&P – (a) xDSL; (b) Cable; (c) FTTB; (d) FTTH.

Fig. 3 shows a large difference in traffic volume between the total upload and download throughputs. In all cases, the throughputs in both directions are constant based upon channel selection; however, the upload traffic volume is minimal compared to the download. The upload traffic consists of light packets, 60~90 bytes in size, for the signaling purpose to acknowledge the received video packets. Unlike P2P IPTV, the upload performance of the access technologies shows no impact on the overall quality of the IPTV STB services. For IPTV service providers, it is important to manage the download throughput (by limiting VoD server) below the maximum reachable rate of the lowest bandwidth subscriber links, such as 6.8 Mbps of xDSL in this paper. To avoid any confusion, the first 5 minutes in Fig. 3 (a) implies the time it takes to choose the designated channel for experiment; thus, this does not refer to playing delay.

### *C. Packet Size Distribusion*

The two groups in packet size distribution were formed in the P2P IPTV traffic [3, 5]. We also observed a similar pattern in IPTV STB services. Fig. 4 shows the percentile of packet size distribution in the collected traces. In all graphs, 60% of the total packets belong to 1500-bytes bin while the rest resides in 60- and 90-bytes bins. There exist two types of packets: signaling and video. Signaling here refers to the acknowledgement message to the received packets and sequence control. Fig. 5 also illustrates the grouping pattern in packet-size arrival sequence as two continuous dense regions at 1500 bytes and 60 bytes on the y-axis. This concrete pattern contributes to the occupancy of Mice and Elephant traffic [14] in the Internet. In addition, the packet size distribution of streaming type is identical to these D&P services.

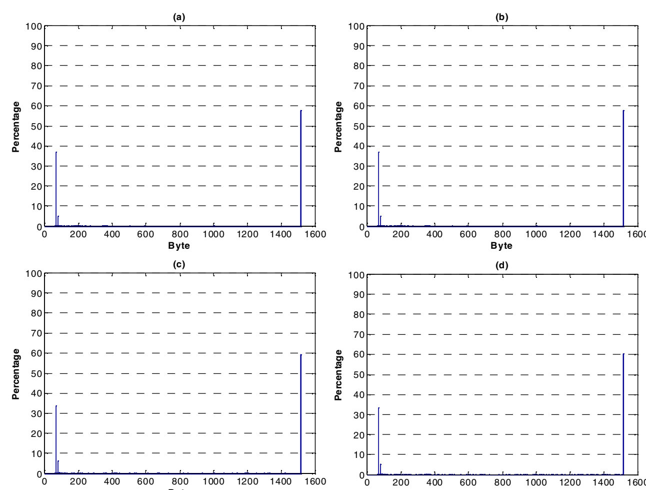


Figure 4. Packet size distributions for D&P – (a) xDSL; (b) Cable; (c) FTTB; (d) FTTH.

To measure self-similarity, the Hurst parameter [12] of video transmission traffic, packet-size arrival sequence, was computed where H = 0.55. It is difficult to conclude that the video traffic is self-similar. Its autocorrelation graph in Fig. 6 also shows that its distribution is highly random. In fact, the Poisson distribution cannot represent the IPTV traffic of bursty period accurately.

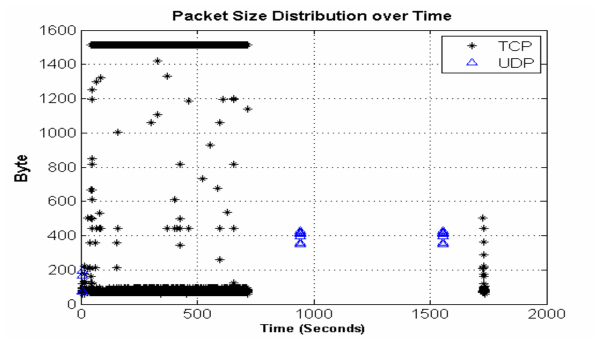


Figure 5. Packet size distribution according to arrival sequence in IPTV session.

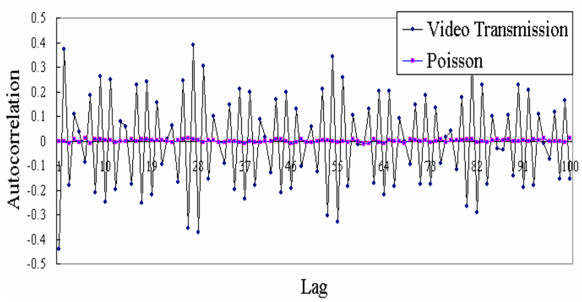


Figure 6. Autocorrelation for video traffic and Poisson distributed values.

## D. *Traffic Demand Cycle and Packet Reordering*

The basic operations of IPTV separate into channel surfing and viewing activities. Regardless of streaming or D&P, the IPTV VoD services in this paper do not encounter the traffic burst by channel surfing and corresponding channel zapping delay. They engage in channel selection rather than channel surfing. Fig. 7 shows the traffic bandwidth fluctuation while watching two consecutive episodes via Cable. Its fluctuation cycle appears regularly, two peaks of 7 Mbps, in which the traffic burst is followed by each channel selection. The grey regions (vertical lines) in the graph represent the small traffic volume during the channel selection. We observe that no significant traffic volume (e.g., 2 Kbps), is generated during channel selection process unlike multicast live TV.

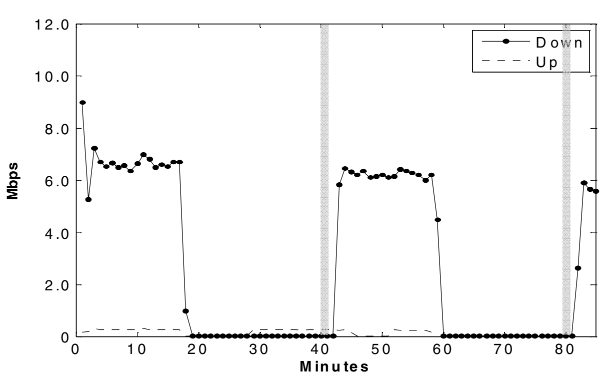


Figure 7. Throughput pattern while watching two consecutive episodes.

TABLE III. PACKET REORDERING RATIO (OUT OF ORDER AND RETRANSMISSION PACKETS) DURING IPTV DELIVERY

| | **Reordering Packets** | | |
|---|---|---|---|
| | ***Retransmission*** | ***Out of order*** | ***Total*** |
| xDSL (D&P) | 2289 (0.2%) | 36,891(4%) | 885,349 |
| Cable | 381 (0%) | 126,564 (8%) | 1,495,370 |
| FTTB | 2224 (0.2%) | 34,939 (4%) | 880,208 |
| FTTH | 1604 (0.1%) | 36,467 (4%) | 893,163 |
| xDSL (streaming) | 20 (0%) | 0 | 581,393 |

Table III shows the packet reordering in the monitored IPTV sessions by counting retransmission and out-of-order delivery packets accordingly. Despite of the packet reordering at the client domain, the video quality is not degraded and these ratios are tolerable over TCP. IPTV over Cable experiences slightly more out-of-order ratio (8%) than the others. It had to go through the additional Cable provider's network while the others stay within the same ISP's network which provides IPTV services as well. The QoS problem may rise for the IPTV providers if more users in separate access networks subscribe to their IPTV services. Interestingly, VoD streaming service which offers less of an SD quality does not experience any reordering during the entire monitoring period. For now, we conclude that the broadband access type itself does not have a significant impact on the packet reordering.

# IV. BANDWIDTH DEMAND FORMULAS FOR IPTV VOD

Based on the above observations, we have formulated the representation for bandwidth demand in IPTV VoD services. Our approach begins from the practical matter that the majority of broadband subscribers are still relying on low-bandwidth xDSL technologies. The proposed formulas differ from the previous IPTV bandwidth estimation models [5, 8] in the following aspects:

*a) The bandwidth at the client domain does not correspond to the required SD or HD transfer ratios. The allocated bandwidth for IPTV varies depending on the types of broadband access networks, VoD server configuration, and network conditions.*

*b) The proposed formulas describe the IPTV VoD services by D&P delivery architecture which has not been proposed in any other work.*

*c) The traffic burst due to channel surfing is negligible in this VoD architecture.*

*d) The running time of each channel is fixed and known. The occurrence of VoD traffic is not continuous but an independent discrete event.*

*e) Channel viewing time does not necessarily coincide with the packet transmission time between the server and STB.*

## A. *Channel Selection Process*

Zipf's law [11] describes the user behavior of selecting the popular channels in ranking where twice as many of viewers participate in the i^th^ popular channel than i-1^th^ channel. From the perspective of bandwidth in VoD, the channel priority can be expressed using aggregated groups of the video file sizes, $f_k$ accordingly where $k$ refers to the group index. In other words, we interpret the channel selection as who is choosing file size, $f_k$, rather than who is watching channel $i$ for a fixed bandwidth. Thus, we use the file size as an additional constraint in the Zipf channel selection process. The probability of choosing channel $k$ with file size $f_k$ is $p(k, f_k)$:

| | |
|---|---|
| $k$ | Channel file size groups |
| $f_k$ | Video file size of group *k, where k = 1,2,3 …* |
| $z_i$ | Probability of choosing i^th^ popular file size group *k* |
| $p_k$ | Popularity of channel file size group *k* |

$$\sum_k p(i, fk) = z_i \quad \text{and} \quad \sum_i \sum_k p(i, fk) = p_k \tag{1}$$

In our measurement environment, the 40-minute episode is about 850 Mbytes with SD quality encoding. Implicit values for distribution of channel file sizes can be used in applying Formula (1) of channel selection probability. Thus, the VoD channels in HD quality can be easily expressed by replacing larger file sizes.

## B. Bandwidth Demand Formulas

The throughput rates in real IPTV networks are sampled according to the type of broadband access networks. The sampled values in our measurement environments are 11, 10, 7, and 7 Mbps for FTTH, FTTB, Cable, and xDSL, respectively. $D_j(t)$ is a random variable which represents the bandwidth demand of a single STB (viewer $j$) at time t. It indicates whether the download of movie content is terminated after the channel selection at time. If it indicates zero, the bandwidth is no longer required for viewing the remaining time of the channel because the content is already delivered to the STB. In our measurement result, the file transfer is completed within the average 1/2 of the channel running time after the viewing starts. It is defined by:

| | |
|---|---|
| $j$ | A single viewer *j* |
| $r_l$ | Throughput rate between VoD server and client via media *l*, where $l \in \{xDSL, Cable, FTTB, FTTH\}$ |
| $T_{jk}$ | Time that viewer j started to download channel file size *k* |
| $\tau_{kl}$ | Duration of downing program file *k* by medium *l* |
| $C_{jk}$ | Time that viewer *j* stopped to play channel file size *k* (a new arrival of channel selection) |

$$D_j(t) = \begin{cases} r_l & \text{if } T_{jk} \le t \le T_{jk} + \tau_{kl} \\ 0 & \text{otherwise} \end{cases} \quad \text{where } \tau_{jk} = \frac{f_k}{r_l} \tag{2}$$

The bandwidth demand for VoD at time t, $Bv(t)$, is bandwidth estimation of all active viewers during the actual download period. $I_j(t)$ is an indicator function whether the viewer stays in the same channel at time t that he/she originally chose. Thus, $Bv(t)$ is defined by:

| | |
|---|---|
| $h$ | Active household STBs |
| $I_j(t)$ | A indicator function of t, which is 1 if viewer j is on at time t, otherwise 0. |

$$Bv(t) = \sum_{j=1}^{h} Dj(t)\, Ij(t) \tag{3}$$

## C. Simulation Results

We simulate the proposed model on the dedicated links where the IPTV server farm supports 200 active viewers. To simplify the viewer behavior for IPTV VoD subscribers, we assume that every viewer stays in the channel of their choice until it terminates. The arrival of channel selection requests per unit time follows a Poisson distribution. Formula (4) describes the channel selection arrivals and its expected value as follow:

| | |
|---|---|
| $m_{t,\phi}$ | Number of channel selection requests by the viewers during the time period $(t, t+\Phi)$ |
| $\lambda$ | Mean number of requests by viewers per unit time |

$$P(m_{t,\phi}) = \frac{e^{-\lambda(\phi)} \lambda^{m_{t,\phi}}}{m_{t,\phi}!} \quad \text{and} \quad E[m_{t,\phi}] = \lambda\phi \tag{4}$$

Table IV illustrates the channel popularity and corresponding file sizes used in the simulation. The targeted IPTV service in this paper has a majority of channels with 1-hour length content (1,000 MB in file size with 34.1% occupancy) because it mostly consists of reruns of popular TV shows. Our assumption has made over SD quality encoding for now. Table V shows the sample throughput rates for each access networks and its penetration ratio where 60% of the IPTV subscribers rely on xDSL.

TABLE IV. CHANNEL POPULARITY

| File Size (MBytes) | 2000 | 1500 | 1000 | 500 | 250 | 200 |
|---|---|---|---|---|---|---|
| Playing Duration (Minutes) | 120 | 80 | 60 | 30 | 15 | 10 |
| Popularity | 11.38% | 17% | 34.1% | 8.53% | 6.82% | 5.7% |

TABLE V. DETAILS OF RESIDENTIAL BROADBAND ACCESS NETWORKS

| Access Network | xDSL | Cable | FTTB | FTTH |
|---|---|---|---|---|
| Sample Throughput Rate (Mbps) | 6 | 7 | 10 | 11 |
| Penetration Ratio | 60% | 10% | 20% | 10% |

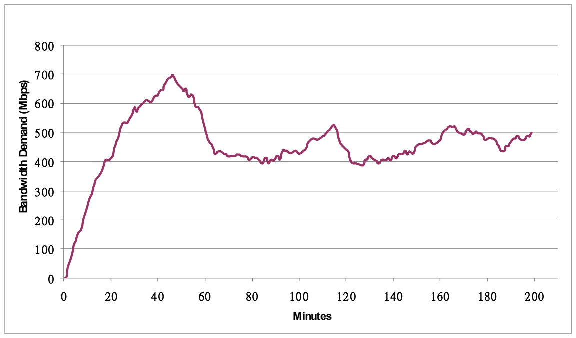


Figure 8. Mean estimated bandwidth demand for IPTV D&P services.

Based the above conditions, we have taken the mean of the estimated bandwidth simulations. Fig. 8 shows the bandwidth demand over 3 hour period. The initial peak reaches up to 700 Mbps, and then it gradually reduces to average 500 Mbps. [5] shows that the average 1,000 Mbps is required for 200 active viewers in a multicast live TV environment. Although the assumptions in that research cannot be a direct comparison to our simulation, there may be a possible bandwidth gain from IPTV VoD service where it does not require a constant and fixed throughput rate in play (e.g., SD = 3.75 Mbps, HD = 15 Mbps).

## V. CONCLUDING REMARKS

While delivering fiber to households is still in infancy, the IPTV services by the D&P approach is an affordable choice for Telcos. This paper presents the commercial IPTV traffic characteristics via various residential broadband access networks. We have observed that the high rate traffic burst appears at the initial minutes of channel viewing time. The throughput rates vary depending on the subscriber's access network. Thus, the traffic volume shows different patterns for each network. The packet size distribution in IPTV using STB follows a similar behavior of P2P IPTV. In addition, we analyzed the packet reordering ratios in IPTV sessions under the tolerable video quality condition.

Based on the observations from the real-world measurements, we proposed the mathematical formulas to represent the bandwidth demand for multiple users via various broadband access networks in IPTV VoD services. Due to the difference in traffic nature from multicast live TV, the proposed formula is much simpler than the previous IPTV modeling by others.

For future work, we plan to analyze the impact of IPTV on the existing traffic in the bundled service environment. Accurate traffic modeling and analysis techniques for bundled service traffic will be investigated.

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