Analysis and Modeling of Multimedia Workload Characteristics in a Multi-service IP Network

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***Abstract*—The Internet is a prevailing network infrastructure for integrating broadcasting, telecommunications and data communications. Multimedia services such as IPTV and VoIP achieve economy of scale in many countries and the number of subscribers is increasing fast. As multimedia applications become pervasive in the Internet, the characteristics of IP traffic mix has changed. Workload characterization is one of the most important steps in IP traffic engineering to deploy and provision an efficient network. However, traffic characteristics in commercial multi-service IP networks are not known well because the necessary data sets are rarely available. This article presents analysis and statistical modeling results of multimedia workload characteristics in a nationwide commercial IP network in Korea. We first survey trend of broadband Internet service market and growth of multimedia services in the network. To investigate the workload characteristics we analyze service log information and find session-level traffic models for the multimedia services.**

I. Introduction

The Internet has become the prevalent network infrastructure for integrating broadcasting, telecommunications and data communications. Internet Service Providers (ISPs) are striving to expand their market beyond the broadband Internet service. As a result multimedia services such as IPTV and VoIP are widely deployed in many countries and the number of subscribers is increasing fast. For example, while the number of broadband Internet subscribers is 7.2 million in KT Corporation, the number of subscribers of IPTV is approximately 1.5 million and that of VoIP is 1.6 million as of May 2010. It is reasonable to expect the continued growth of multimedia services in IP networks.

Multimedia traffic comprises a substantial part of the Internet traffic. Recent studies show a notable shift in the Internet traffic from web to multimedia content [1]. There have been extensive studies of web [2] and on-demand or live streaming workloads on the Internet [3]. For IPTV multicast traffic, [4] presents analysis results on packet-level traffic in a commercial IP network in Italy. For video-on-demand (VOD) system, [5] reports user behavior and content access patterns. The authors observe user arrival rate, session duration, and content popularity based on the service log data.

This article deals with the multimedia workload characteristics in an integrated services Internet that provides commercial IPTV and VoIP services in Korea. We first survey the evolution of broadband Internet service and trend in dissemination of multimedia applications in KT Corporation. Based on (anonymized) IP address information we examine the traffic mix of the Internet and analyze the contribution of multimedia traffic. To verify the workload characteristics for multimedia applications, we collect service log data and find traffic models for request arrivals, session durations, and contents access patterns. In case of IPTV, VOD service requests directly occupy network bandwidth whereas watching multicast live TV channel does not if a multicast tree is already set up, which is the case in our network. Thus we focus on the VOD traffic only in this article.

We find that the service request process follows a Poisson distribution for VOD and VoIP services. The session duration process for VOD is closely related with contents length. It follows an exponential distribution for the extent of average length of contents. An interesting finding is that session duration process for VoIP calls has a long tail.

Workload characterization is one of the most fundamental steps in IP network engineering to provision an efficient network. Traffic characteristics in commercial multi-service IP networks are, however, not known well because (i) the introduction of multimedia services is rather up-to-date and (ii) the necessary data sets from an operational network are rarely available [6]. Our findings on the workload characteristics for IP multimedia applications will be helpful to dimension capacity in network planning and other network engineering practices.

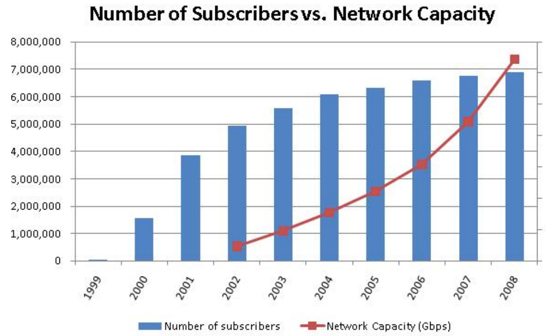

Fig. 1. Trend in number of broadband Internet subscribers and network capacity during 1999 - 2008

II. Trend of Broadband Internet Service Market

We first the survey evolution of broadband Internet service in KT Corporation. Figure 1 shows trend in the number of broadband Internet subscribers and change of network capacity during the past decade[1]. It is shown that the number of subscribers grew rapidly in early 2000's. While the growth rate in the number of subscribers has slowed down as the Internet service market has become saturated, the network capacity has increased exponentially during 2005 - 2010. With a flat-rate system, revenue of an ISP is directly proportional to the number of subscribers. If the number of subscribers grows little, then the increase of revenue is restricted especially in a highly competitive and saturated market. Contrarily the rapid increase in network capacity requires a large amount of investment. Thus we ascertain that there exists a discrepancy between the growth rate of network capacity and the number of subscribers and that ISPs are having to invest in the network more than the revenue that they can expect to earn from the increase in the number of subscribers.

The increase of Internet traffic is attributed to the proliferation of file sharing applications and multimedia services. File sharing applications such as BitTorrent and eDonkey are popular in Korea and contribute to the drastic growth of the Internet traffic in early and mid 2000's. In addition to the peer-to-peer (P2P) file sharing applications, client-server type applications known as web disk (e.g. SkyDrive by Microsoft) are widely used in Korea. According to the preliminary results from a work-in-progress of our own (not published yet), traffic resulting from file sharing applications comprises a majority of the Internet traffic.

Recently, multimedia services such as IPTV have been commercially deployed in many countries. ISPs introduce these multimedia services to compete with cable or media companies and to expand their market beyond the broadband Internet service. KT Corporation introduced IPTV service in 2007 and massive transition in telephony service from Plain Old Telephone Service (POTS) to VoIP started in 2009.

IPTV provides live TV channels, on-demand contents and value-added services such as short message service or web/email access. For the purpose of workload analysis, we consider only VOD service that occupies distinct bandwidth per session. VoIP offers the same functionalities as the conventional POTS. However, it can provide various functions such as video telephony. As POTS is rapidly being replaced by Internet telephony, the number of VoIP subscribers is increasing fast. The increase of IPTV and VoIP subscribers in KT is shown in Figure 2.

[1]The network capacity is given by the sum of bandwidths of links that connect subscribers and the Internet backbone.

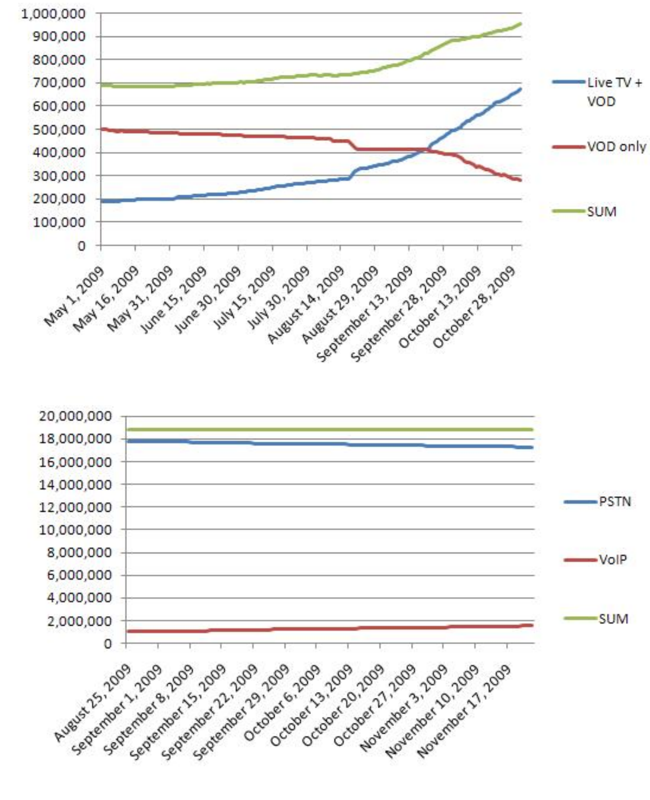

Fig. 2. Growth in the number of subscribers for IPTV and VoIP services. (Top) IPTV (Bottom) VoIP

III. Analysis and Modeling of Multimedia Workload Characteristics

This section describes statistical analysis results on workload characteristics for IPTV (VOD) and VoIP services. The workload can be characterized at different levels such as user, session or protocol. In this article, we are interested in modeling the workload characteristics at the session level. A session corresponds to a VOD request for IPTV or a voice/video call for VoIP. Modeling the session level behaviors requires specifying arrival and duration of a session.

We use one weekday service log information from April 2009 for analysis of the multimedia workload characteristics. The service logs were generated for every VOD request or VoIP call. Service logs were originally recorded for billing purposes thus they are fairly accurate. As shown in this section, the number of logged requests for each service is more than a million. We believe that the data-sets are sufficiently large for statistical analysis. The logs for VOD service contain the following information per each request. Customer identity, IP addresses, and content names were anonymized for privacy reason.

- Type of service (media transmission)
- Request start time and end time
- Subscriber ID
- Media server and set-top box IP addresses
- Content name
- Encoding rate of contents (Mbps)

The logs for VoIP service contain the following information per each request:

- Type of service (Voice or Video)
- Request start time and end time
- Terminal equipment ID
- Phone number of calling/called terminal equipment
- IP address of calling terminal equipment
- Data rate of the call (Kbps)

From these service logs, we make a session-level description of VOD and VoIP services containing start time, duration, required bandwidth, and size of transferred data. The number of subscribers for IPTV and VoIP services are 709,778 and 504,649 respectively. The number of logged requests for IPTV and VoIP are 6,743,035 and 3,909,345 respectively. The number of subscribers for the Internet service was 6.8 million in April 2009 and the penetration ratios of IPTV and VoIP are 10.5% and 7.5% respectively.

A. Distribution of Contents Length

Since the holding time of VOD service is closely related with its contents length, we examine the distribution of content length. The total number of VOD items was 124,796 in April 2009. VOD contents are grouped into two categories based on the encoding rate: standard definition (SD) and high definition (HD). The data rate of SD contents is less than 3 Mbps while that of HD contents is above that rate, up to about 10 Mbps. Most of the contents are of SD (102,145) and less than 20% of the contents are of HD (22,651). The average length of SD contents is 27.84 minutes and that of HD contents is 36.96 minutes. The average length of overall VOD contents is 29.49 minutes. The maximum contents length is 260.48 minutes.

The length of VOD content ranges from a few seconds to 4 hours and 20 minutes. The short content items mostly consist of commercials and preview programs. Fig. 3 shows the complementary CDF of contents length distribution. We also draw a quantile plot (or probability plot) in which the theoretical quantiles are plotted against the order statistics for the given data. Thus, we plot the $x_{(i)}$ on one axis and

$$F^{-1}\left(\frac{i-0.5}{n}\right),$$

on the other axis, where $F^{-1}(\cdot)$ denotes the inverse of the cumulative distribution function for the hypothesized distribution. Figure 4 shows the quantile plot of VOD contents length vs. exponential distribution. The distribution of VOD contents length shows some deviation from exponential distribution when the length is larger than 3,000 seconds.

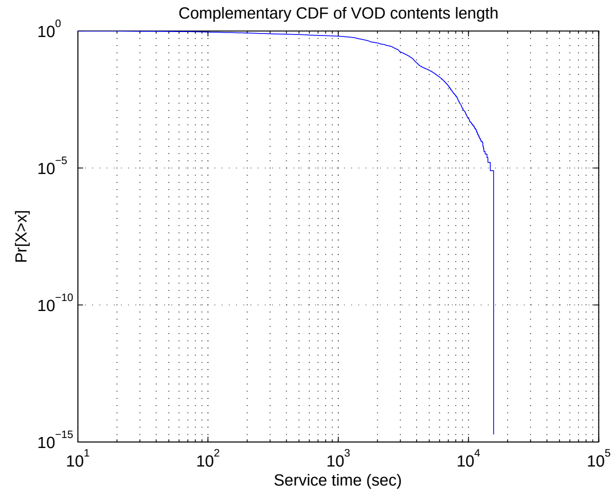

Fig. 3. Complementary CDF of contents length

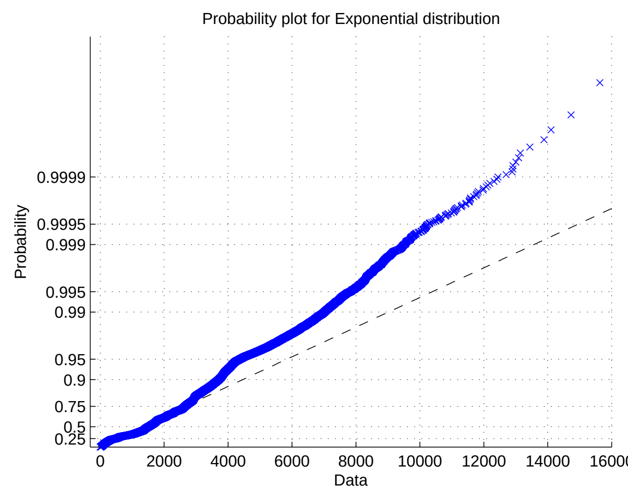

Fig. 4. Quantile plot of contents length vs. exponential distribution. X quantiles correspond to the VOD contents length and y-axis denotes the inverse of the cumulative distribution function for exponential distribution.

B. Session Arrival

Service log information records arrivals of VOD requests or VoIP calls on a scale of second. Thus there are many concurrent calls or service requests in busy hours and computation of interarrival time is not possible. We use Poissonness plot that can verify the discrete data follow a Poisson distribution. It also serves to highlight which points might be incompatible with the model. The Poissonness plot is drawn with discrete variable obtained by counting the number of times something occurs. In our case, the number of occurrence corresponds to the number of request arrivals in a given time interval. The counts are denoted as k, with $k = 0, 1, ..., L$ where L is the maximum observed value for our discrete variable in the data set. Then the total number of observations in the sample is

$$N = \sum_{k=0}^{L} n_k,$$

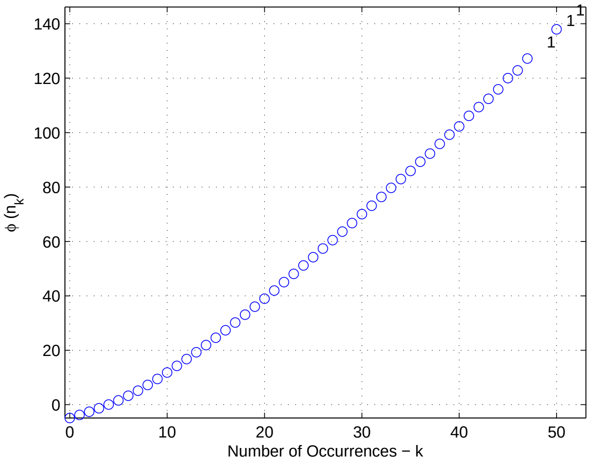

Fig. 5. The Poissonness plot for VOD service request arrivals

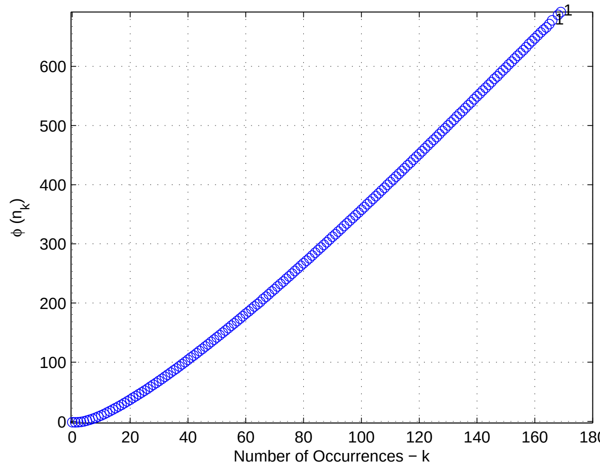

Fig. 6. The Poissonness plot for VoIP service request arrivals

where n_k represents the number of observations that are equal to the count k.

A basic Poissonness plot is drawn by plotting the count values k on the horizontal axis and

$$\varphi(n_k) = \ln(k!n_k/N)$$

on the vertical axis. These are plotted as symbols, similar to the quantile plot. If the given data follow a Poisson distribution, then the Poissonness plot follows a straight line. Systematic curvature in the plot would indicate that these data are not consistent with a Poisson distribution. The values for $\varphi(n_k)$ tend to have more variability when n_k is small. Figure 5 shows the Poissonness plot for the VOD request arrivals. We observe that the given data follow a Poisson distribution quite well. The average arrival rate is 14.09 requests per second.

Figure 6 shows the Poissonness plot for VoIP connection arrivals. We observe that the given data follows a Poisson distribution in this figure. Most of the VoIP service connections are voice calls and video calls comprise only 0.06% of all the connections. Thus we do not separate VoIP service connections and analyze them as a whole. In Figure 6, we observe that VoIP connection requests can be modeled by a Poisson distribution. The average arrival rate is 26.27 connections per second.

C. Holding time

We next look into the holding time distribution of VOD service. The total number of VOD requests on the day is 6,743,035, which is the largest number of such requests collected in a day appearing in the scientific literature, to the best of our knowledge. A million logs are used in our analysis for easier and faster data processing. We believe that one million logs are sufficiently large enough to get statistically meaningful results. Among these service logs we eliminate logs for abnormal termination, of which service duration is recorded as 0 second. The number of abnormal termination logs is 24,532 (2.34% of the total logs). In addition, there are also some exceptionally long holding time ranging to 24 hours (46 logs). Though it may happen in reality, it is rare and does not contribute to the determination of distribution. We restrict the VOD service time to the maximum of the contents length. The mean holding time is 22.50 minutes.

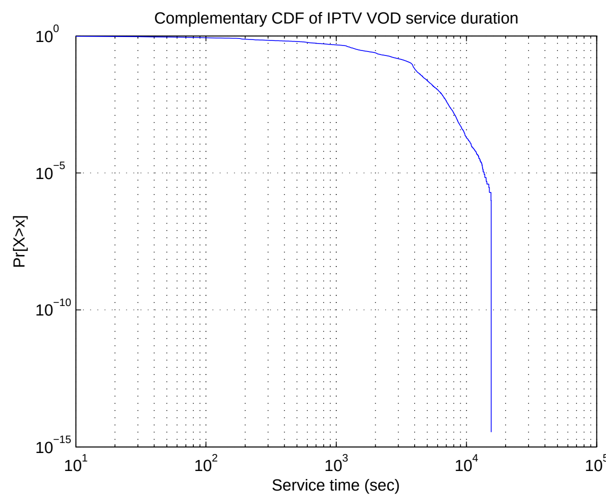

Fig. 7. Complementary CDF of VOD service time

The complementary CDF of holding time is shown in Figure 7. In this figure we observe that the holding time distribution looks like the contents length distribution. In addition, we show the quantile plot of VOD service time vs. exponential distribution in Figure 8.

The total number of VoIP service connections is 3,909,345. A million logs are also used in the analysis. The mean holding time is 1.78 minutes and the maximum is 256.18 minutes. We draw the complementary CDF of holding time for VoIP service in Figure 9. In Figure 10 we also draw the quantile plot vs. lognormal distribution.

IV. Related Work

For the last decade, VOD and VoIP have long been cited as examples of new Internet applications by networking researchers. However, due to the lack of a large-scale real world data set, (i) researchers are typically inclined to rely

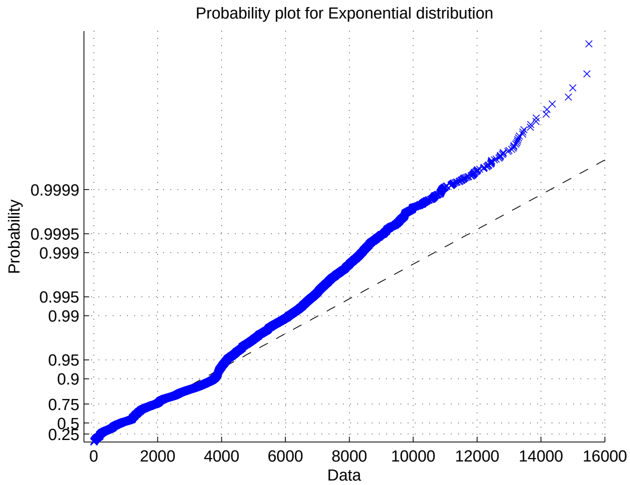

Fig. 8. Quantile plot of VOD service time vs. exponential distribution. X quantiles correspond to the VOD service time and y-axis denotes the inverse of the cumulative distribution function for exponential distribution.

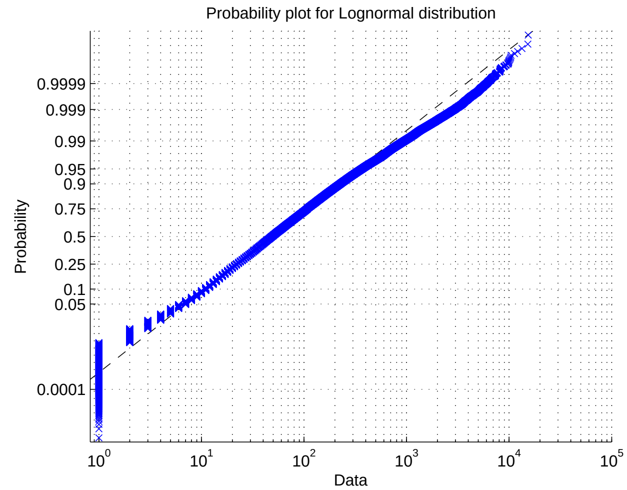

Fig. 10. Quantile plot of VoIP service time vs. lognormal distribution. X quantiles correspond to the VoIP service time and y-axis denotes the inverse of the cumulative distribution function for lognormal distribution.

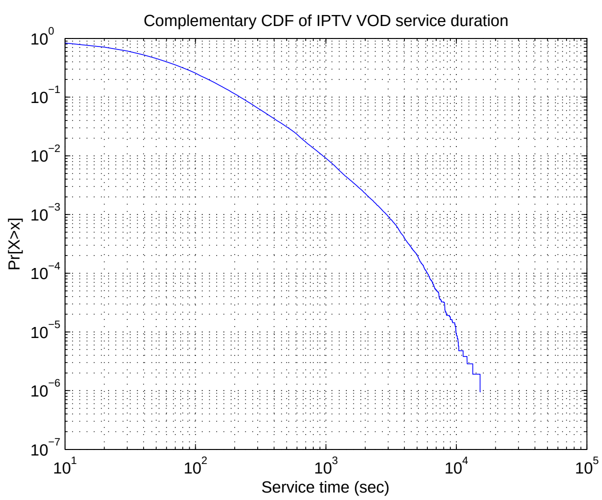

Fig. 9. Complementary CDF of VoIP service time

on simulated models to drive their design and developmental efforts, and (ii) there have only been a few in-depth studies on characterizing workload of those services.

Recently, several studies have characterized P2P-TV, P2P-VOD traffic on the Internet to understand the benefits of peer-assistance in alleviating the bandwidth requirements on servers [7], [8], [9]. Cha et al. [10] explored how users access videos in the YouTube system. Huang et al. used the VOD server logs of MSN video and characterized the VOD traffic to explore the potential for peer-assisted VOD service [11]. However, because those P2P-TV, P2P-VOD, YouTube, and MSN Video systems are accessed through the general Internet, system response to user interaction is often delayed, probably causing users to demand less interaction than they might desire. In order to exactly understand how much interaction users want, we need a data set collected in a more responsive, well-provisioned, and large-scale operational environment.

Cha et al. [12] and Qiu et al. [13], [14] have measured and modeled user activities and channel popularity or switching dynamics in a large-scale IPTV system, but what they have focused on were Live (Multicast) TV sessions, not VOD ones, where user access patterns have a direct impact on the VOD servers.

Yu et al.'s [5] is the closest work to our own, as they conducted an extensive empirical analysis of access patterns and user behaviors in a large centralized VOD system in China Telecom. They had collected more than 21 Million VOD requests from 1.5 Million broadband Internet users (with 512 Kbps to the home), covering a total of over 6,700 unique video files for the 219 days, from May to December 2004. Interestingly, a key finding of their study was that user requests arrival distribution looks more similar to the Poisson distribution (with lambda = 15) as the arrival rates gets higher (when the number of requests >= 5/sec.), which is congruent with our results in Fig. 5, with lambda = 14.09. While their measurement study was done at one or two magnitudes smaller scale VOD system than ours in terms of (i) the number of requests (70-120 K vs. 6.7 M requests per day), (ii) users' access link bandwidth (512 Kbps vs. 5-100 Mbps), (iii) the number of video contents being provided (6,700 vs. 124,800 unique video files), and (iv) the quality of video contents (encoded and played back at a few hundred Kbps vs. a few to 10 Mbps), we confirmed that the results still remain almost the same.

We also found that VoIP call arrival process, even in a full-IP network, can still be modeled as a Poisson process and call durations have a long tail, which conform to the recent results of Birke et al.'s measurement work done at a commercial ISP backbone link in Italy [15].

V. Concluding Remarks

This article deals with the workload characteristics in an integrated services Internet offering commercial IPTV and VoIP services. We briefly survey the evolution of broadband Internet service and dissemination of multimedia applications of KT Corporation. We collect service log data and find traffic models for request arrivals and session durations, and contents access patterns. From the statistical analysis results, we find that the service request process follows a Poisson distribution for VOD and VoIP services. The session duration process for VOD can be approximated by an exponential distribution for the range of average length of contents (around 30 minutes). An interesting finding is that session duration process for VoIP calls has a long tail. We believe that our findings on the workload characteristics for IP multimedia applications can be applied to dimension capacity in network planning and other network engineering practices.

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