

# Traffic analysis and characterization of Internet user behavior

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**Abstract**—Internet usage has changed, and the demands on the broadband access networks have increased, both regarding bandwidth and QoS. Characterizing the traffic, as seen by a broadband access network, can help understanding both the demands of today and the demands of tomorrow. In this paper we analyze traffic measurements from a Swedish municipal broadband access network and derive corresponding user behavior models. The paper focuses on Internet usage in terms of traffic patterns, volumes and applications. Also, user activity characteristics, as session lengths and traffic rate distributions, are analyzed and modeled. Notably, the resulting models for user session lengths turn out different than traditionally assumed.

**Index Terms**—Measurements; Characterization techniques; user behavior; Internet applications

## I. INTRODUCTION

Internet usage is evolving from the traditional World Wide Web (WWW) usage to triple-play usage, where households may have all their communication services through their broadband access connection. The challenge then becomes to design the broadband access networks so that they can deliver services requiring strict QoS demands, such as IP-TV, at the same time as capacity for unpaid traffic (from the operator's perspective), for example file sharing, is demanded by the users.

One important part in meeting this challenge is to determine and understand Internet usage. Traffic patterns and applications need to be investigated and reported on. Here it is worth noting that traditional traffic measurements on aggregated traffic at the IP level do not serve this purpose. In order to capture user behavior and traffic patterns in broadband access networks, the measurements need to both be performed close to the users and be able to identify specific applications.

A number of papers have presented traffic measurements focusing on Internet applications. In most of the papers, the measurements have been performed on a high speed link in the backbone, and not in the actual broadband access network. In [1] several challenges were discussed for high speed network measurements and monitoring, for example the legal issues of storing data. The investigation in [2] presented measurements from the Sprint IP Backbone, while [3] presented measurements from seven major Japanese ISPs. These measurements were further analyzed in [4]. Peer-to-peer (P2P) traffic has been the focus of some papers, for example, [5] and [6]. The problem with measuring aggregated traffic in a backbone is

that the user behavior is not available. In order to capture detailed user behavior, the measurements need to be performed close to the users, that is in the broadband access network.

Two papers that investigated streaming traffic generated by home users are [7] and [8]. In [9] traffic data from a Brazilian live streaming media server was analyzed, while [10] investigated statistical properties of aggregated Asymmetric Digital Subscriber Line (ADSL) broadband access traffic. Internet usage in wireless access networks was investigated in [11], where measurements from a campus wireless access network at the University of North Carolina were presented and analyzed.

However, only a few papers describe measurements that are similar to the measurements in this paper. In [12] user sessions in a Brazilian broadband access network were analyzed. Further, the investigations in [13], based on measurements from 1300 ADSL users in France, showed that most of the users have a low utilization of their bandwidth, mainly due to the P2P applications that limit the upload rate in the other end. However, 50% of the traffic was unidentified, due to the fact that port-based identification of traffic was used. In [14], with access network measurements from France, the focus was on P2P. A comparison of DSL and Fiber-To-The-Home FTTH user traffic can be found in [4], where the measurements were performed in Japan. However, there are large differences in Internet usage behavior between countries, and thus it is important that measurements from different countries and networks are reported on. Also, [4] is not reporting on specific applications, instead it focuses on the traffic volumes. Application focused measurements in a wireless broadband access network were presented in [15] and [16]

In this article, we present measurements from a Swedish municipal network including about 2600 households with FTTH broadband access. The measurements were performed during May 2009. We have used an advanced commercial monitoring tool, Packet Logic [17], which uses both payload-based and host behavior classification [16] of the traffic, which means that more than 95% of the traffic can be identified.

There are two main objectives with this article. First, we will give a detailed presentation and analysis of modern Internet usage, focused on applications and user behavior. The results will show daily traffic patterns for different application categories, and we also analyze the most popular applications. Both single

hosts and households are used in the analysis. Also, we present some models for user activity, as session lengths and generated traffic volumes. Finally, we show how legal decisions, namely the Swedish enforcement of the European Union Intellectual Property Rights Enforcement Directive (IPRED), may affect the Internet usage behavior. The results in this paper will give a good view on what today's residential users are doing on the Internet. To our knowledge, this is the first time such a detailed characterization of household's Internet usage has been published.

## II. RELEVANT WORK

In [4], a graph of the daily pattern for the aggregated traffic rate was shown. The traffic was asymmetric, with more outbound traffic than inbound traffic, and with a peak time from 9pm until 11pm.

The measurements in [11] were also performed in a university campus network, this time in the US during 2005. About 58% of the traffic volume belonged to web traffic (HTTP), and about 25% was P2P application traffic. Very little streaming traffic was seen in the network, however, the measurements were performed before Youtube was deployed.

Measurements from a German wireless access network with about 250 households were presented in [15] and [16]. The papers mostly used payload-based classification of the traffic during July 2008. The results showed that the Internet applications generating the most traffic were P2P, web browsing and streaming. Also, sessions were identified and modeled. Session durations and volumes could be fitted with lognormal distributions.

P2P traffic was of course reflected in papers that have reported on measurements from other countries. An overview of reports on P2P applications was given in [6]. The measurements were performed during 2003-2004 in Germany and France, and in these reports the most popular P2P file sharing application was eDonkey. In [18], measurements on P2P traffic from 2003 was compared with measurements from 2004. It was shown that between 2003 and 2004, Bit Torrent bit rate increased with more than 100% at the same time as Fasttrack (used by e.g. Kazaa) bit rate dropped, probably due to legal reasons. In [19], eMule and Bit Torrent generated the most P2P traffic, and in [14] eDonkey had the largest traffic volume.

## III. TARGET NETWORK AND MEASUREMENT PROCEDURES

The data presented in this paper was collected from a municipal IP access network in Sweden. The network offers broadband Internet access as well as other services such as IPTV to its customers. However, due to the special implementation of IPTV, which uses multicast addresses, we have excluded IPTV traffic in the analysis. The network is fiber-based, and customers can freely choose among the services offered by the different providers connected to the network. The network uses dynamic IP-address allocation with DHCP. The lease time for the IP-addresses varies with the service provider with the shortest lease time being 20 minutes. It should be noted, however, that we during the investigation

did not have access to the actual IP addresses. All data was anonymized, where each IP address was coded with a unique identification number, using a hash function. This is necessary in order to comply with the Swedish laws on personal integrity.

### A. Measurement tool

The measurements have been performed using PacketLogic (PL) [17], a commercial traffic management device, used in many commercial broadband access networks all over the world. Traffic is identified based on packet content (deep packet inspection and deep flow inspection) instead of port definitions. The device can identify more than 1000 Internet application protocols, and the signature database is continuously updated.

Since the PL is a commercial product, the details of its functions are proprietary. However, the identification process is connection-oriented, which means that each established connection between two hosts is matched to a certain application protocol. When a new connection is established, the identification of this connection begins. The identification algorithm searches for specific patterns, signatures, in the connection. The patterns are found in the IP header and application payload. The identification algorithm uses a tree-like structure of patterns. When the identification starts, the algorithm is in the root of the tree. When certain patterns occur in the traffic, the algorithm moves down in the tree. When it reaches one of the leaves, the full identification is completed.

The PL uses the traffic in both directions in the identification process.

The PL can track and identify several hundred thousand simultaneous connections, storing statistics in a database. It records the short-time average amount of traffic in the inbound and outbound directions as well as the total traffic for all nodes in the network. The data is averaged over 5 minute periods.

### B. Applications

In this article, we have classified the applications into the following categories. *Web Browsing (Web)* is traffic generated by HTTP. *Streaming multimedia* applications will be presented as a single category. Some applications that are included in this category are RTSP, HTTP media stream (HTTP ms), and RTP. The group *Peer-to-Peer (P2P)* consists of P2P applications that are mainly used for file sharing. Some examples are Bit torrent (BT), Direct Connect (DC), eDonkey, Kazaa, Gnutella and PeerEnabler. The category *File transfer* consists of applications as FTP, used for raw download of files. *Online gaming (Game)* applications provide multiplayer online games, on all platforms. Many games are included in this category, where two popular examples are World of Warcraft (WoW) and Half-Life. *Messaging and collaboration (M/C)* applications will enable people to send messages and talk over Internet. Applications for email, instant messaging, and Voice over IP belong to this category. Some examples are MSN messenger, IMAP, SIP, MGCP, Skype, and Ventrillo. *Other* applications are, for example, SSH and SSL. Also, applications related to network management belong to this category.

Data which is not consumer generated represents a very small part of the total traffic ( $< 1\%$ ) and has thus been excluded from the analysis.

### C. Measurements

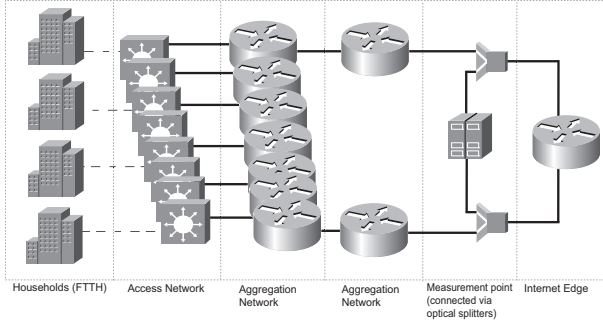


Figure 1. Conceptual overview of the Municipal network architecture for FTTH. The dashed lines denote 100 MB/s links and the solid lines denote 1 Gb/s links

Approximately 2600 FTTH households were included in the measurements. These households are spread all over the town, representing many demographic groups and household constellations. Internet speeds range from 1 Mb/s to 100 Mb/s, depending on which service the customers have chosen.

The measurement equipment was connected to the network via optical 50/50 splitters, see Figure 1. The optical splitters merely split the optical signal into 2 exact copies, so that the traffic in the network is not affected by the measurement device. The measurement point is the Internet Edge (IE) aggregation point, where the service providers are connected to the network. Since there are 2 redundant links to this node, a measurement hardware with 2 physical GBEthernet channels has been used. The measurements were performed during the whole of May 2009.

The main parts of the analysis were performed on hosts (IP addresses). Since one household can have several users, and thereby, several hosts, it is not possible to separate households in these analyses. Therefore, we also performed a detailed analysis of households parts of the network. In this study, comprising of a total of 1178 households, we also registered data from the DHCP server used to provide network addresses for users. The DHCP server logs data concerning date and time, IP address, service provider, access switch and access port. This data was combined with the IP address based data from the PL in a MySQL database, which meant that households with difference access speeds could be separated. It is worth noting that the online time of a household is measured in 5-minute periods. Thus, if the household has sent or received traffic during a 5 minute period, it is classified as active for 5 minutes. Also, data is truncated at 300 kb or 37.5 kB for this 5-minute period. If below this threshold, data is truncated to zero, and thus not included in the statistics.

## IV. AGGREGATED TRAFFIC CHARACTERISTICS

The aggregated traffic measurements show the general traffic patterns in the network. For a network operator it is

important to understand how the traffic varies during the day. Service and maintenance work need to be performed during times of low traffic. For example, in the municipal network in this article, a service window is used between 2-4am with certain time intervals. During this service window, software and hardware updates and installations are performed.

### A. Traffic volumes

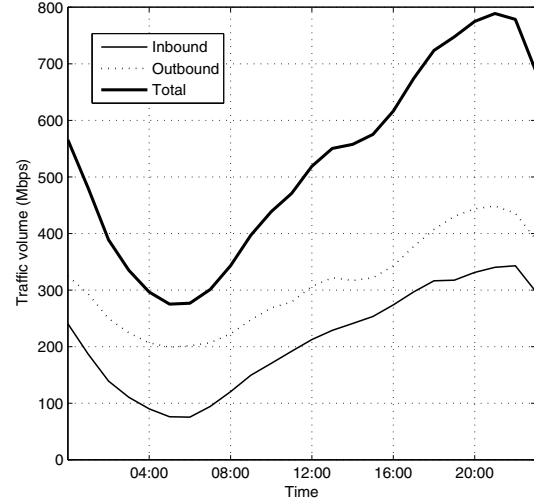


Figure 2. Average daily total traffic volume (Mbps)

Figure 2 shows the aggregated daily traffic pattern for the network, averaged over the measurement period. A total of 158 Tbytes of monitored data is included in this graph. The traffic patterns for weekdays and weekends are very similar. As can be seen, the peak time is from 7pm until 10pm. In the weekends, the peak time starts slightly earlier, however the average traffic volumes are about the same. Also, the traffic is asymmetrical, with more outbound traffic than inbound traffic. As will be shown below, this is completely due to P2P file sharing traffic. This asymmetrical behavior will have an effect on the design of broadband access networks, traditionally implemented as asymmetrical in the *other* direction, see [20].

Table I shows the aggregated traffic analysis when separating households with different broadband access speeds. As can be seen, households with higher bandwidth are heavier users of Internet than households with less bandwidth, both when regarding traffic volumes and time. Households with the highest bandwidth (100/100 Mbps) are online and active in average 500 minutes per day, corresponding to more than 8 hours per day. Households with the lowest bandwidth (1/1 Mbps) are only online and active in average about 1.5 hours per day. Also, as can be seen in the table, households with the highest uplink bandwidth (100/100) do not use the uplink more than households with 100/10 subscriptions.

### B. Applications

Table II shows the traffic volume divided into the different application categories. As can be seen, file sharing traffic dominates, with 74% of the total traffic volume.

Table I  
AGGREGATED TRAFFIC ANALYSIS

Access In/Out Mbps	1/1	10/10	100/10	100/100
No. of households	124	910	101	43
Minutes/day	93	263	388	500
MB/day In	98	693	1879	2319
MB/day Out	32	928	3513	3241

Table II  
TRAFFIC VOLUME RATIOS

	Total	Inbound	Outbound
Web Browsing	5.5%	13%	0.9%
Streaming media	7.6%	16%	1.9%
File sharing	74%	58%	84%
File Transfer	4.9%	3.1%	6.1%
Messaging	1.3%	1.0%	1.6%
Online Gaming	0.5%	1.0%	0.2%
Other traffic	6.2%	7.6%	5.3%

Table III shows the penetration of some well-known Internet applications when separating households with different broadband access speeds. A household is considered to use an application if there is registered data for this application anytime during the measurement period. Of course, the number of households is rather small, which means that the results should be used carefully. However, the results give some ideas on how different households use the Internet. For example, the households with the lowest bandwidth (1/1 Mbps) are not using as many Internet applications as other households. PPLive, mainly used for video and web-TV, is commonly used by households, which means that households are getting accustomed with using the web for video and TV applications.

Table III  
PENETRATION OF APPLICATIONS

Access In/Out Mbps	1/1	10/10	100/10	100/100
Households	124	910	101	43
MSN messenger	25%	52%	77%	70%
Skype	13%	25%	38%	40%
Spotify	12%	18%	34%	37%
PPLive	7%	32%	44%	40%
Joost	6%	13%	21%	12%
iTunes	9%	13%	18%	26%
Google Earth	6%	7%	12%	7%

### C. Cluster analysis

Clustering the end users into different groups is a way to analyze user types. In this article, we have performed a cluster analysis of 1446 households in the network. The amount of data transferred was the chosen parameter for the cluster analysis. The goal was to divide users into groups based on their habits. The results of the cluster analysis are shown in Table IV, where the 10 and 90 percentiles are shown for inbound and outbound traffic data, counted in bytes. We have already shown that the total traffic is asymmetric, with more outbound than inbound.

The clustering analysis shows that this asymmetry is caused by the top users, counted in transmitted bytes. For the less heavy users, the traffic tends to be symmetric or asymmetric in the other direction. To put the numbers into perspective, every household consuming more than 1 GB per day use at least the equivalent of data to download or upload one full length movie per day.

Table IV  
USER CLUSTERS ACCORDING TO TRAFFIC VOLUME

Traffic volume	In GB/day	Out MB/day
90 % bound	2.6	3.2
10 % bound	13	1.1

Another finding in our analysis (not shown in the table), is that the number of applications and protocols used by the heavy users is significantly large compared to the light users. Ranking users according to number of PL protocol signatures used, there is at least a factor of 5 between the top and bottom users.

In [21], our master student performed a cluster analysis for about 2000 households in the same network during September 2007. Comparing his results with the results in this paper, reveals that the number of Internet applications per household is definitely increasing. Today, Internet users are more active than only two years ago, in particular when it comes to the number of applications they are using. Looking at the 90% and 10% bounds in the above mentioned master thesis, we can see some differences between our measurements and the measurements in 2007. While the incoming traffic has increased at both the upper and lower bounds (30% and 175% respectively), the outgoing traffic has decreased at the upper bound (by 26%) and increased at the lower bound (by 120%). Although the users are not exactly the same in the two measurement studies, the results imply that the traffic volume has increased in general (as expected), however the extremely heavy users are significantly less dominating.

### V. FILE SHARING

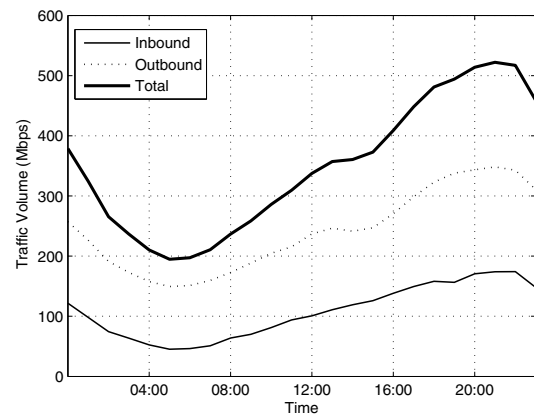


Figure 3. Average daily traffic pattern for P2P File sharing.



It is obvious from both our measurements and other investigations that the majority of the traffic in the access networks is generated by file sharing applications. Therefore, we detail the traffic patterns for file sharing. Figure 3 shows the aggregated daily traffic pattern for the file sharing application category group, averaged over the measurement period. A total of 117 Tbytes of file sharing data was recorded. The file sharing traffic is asymmetric with more outbound traffic than inbound traffic during all hours.

Table V shows the most active applications, when considering traffic volume during the measurements periods. As can be seen in the table, BitTorrent dominates in the network. It is well-known that the top file sharing applications are country-specific, even if BitTorrent is growing in popularity in most parts of the world. Also, the popularity of specific applications have changed during the years, both due to regulatory and legal issues, and due to the launch of new applications.

Table V  
FILE SHARING APPLICATIONS

	Volume ratio
BitTorrent	94%
Direct Connect	5.4%
eDonkey	0.4%
Gnutella	0.1%
Thunder	0.1%
Other	<0.1%

Table VI shows the results for BitTorrent when separating households with different broadband access speeds. About 50% of the investigated households used BitTorrent during the measurement period. As can be seen, households with higher bandwidth use more bandwidth as well. This is clearly shown in the outbound traffic, where households with high bandwidth have high outbound traffic rates, probably due to the design of the BitTorrent protocol.

Table VI  
BITTORRENT

Access In/Out Mbps	1/1	10/10	100/10	100/100
Active households	23	461	71	32
Minutes/day	28	90	158	202
MB/day In	93	568	1279	1104
MB/day Out	76	1300	3386	2388

## VI. WEB BROWSING AND MULTIMEDIA STREAMING

Web browsing and multimedia streaming are activities related to more traditional WWW surfing. Figure 4 shows the average daily web traffic pattern. Both HTTP and streaming protocols are included in the traffic volume. As can be seen, web browsing is mainly performed during the day, which of course not is surprising.

Table VII shows the results for web browsing (HTTP) when separating households with different broadband access speeds. Since web browsing requires an active user by the computer,

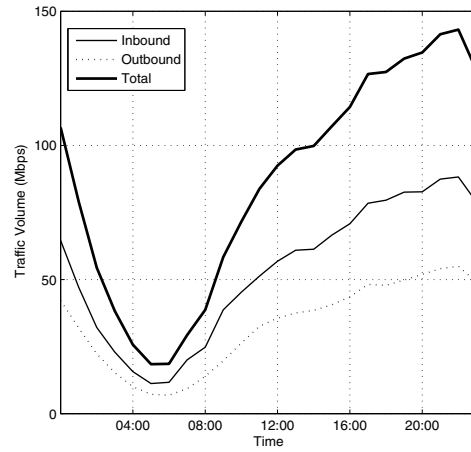


Figure 4. Web traffic pattern.

this table clearly shows that households with higher bandwidth use the Internet more than households with low bandwidth. Households with the lowest bandwidth (1/1 Mbps) use the web in average about 1 hour per day, whereas households with the highest bandwidth use the web in average almost 4 hours per day.

Table VII  
WWW (HTTP)

Access In/Out Mbps	1/1	10/10	100/10	100/100
Active households	123	909	100	43
Minutes/day	59	155	211	228
MB/day In	17	63	85	108
MB/day Out	2.3	9.9	10	9.3

Also, it is interesting to see what type of web sites people visit and download multimedia files from. Therefore, we performed a deep-study analysis of the households, with measurements from May 1 to May 7 2009. We logged the names of the web sites visited, and the amount of traffic that was generated to and from each web site. Note that the log files were totally anonymous, since only the amount of traffic to and from each web site was logged, without any information about the user that generated the traffic. This single week of measurements resulted in more than 100.000 different web addresses. 76 GBytes of traffic was generated (both inbound and outbound).

The sites were then classified into groups, and the results of the analysis are shown in Table VIII. The ratios are calculated in terms of traffic volume related to each group. The main group is multimedia (images, video clips, audio) with 24 % of the traffic. About 15% of the traffic is ungrouped. This traffic belongs to numerous web addresses with very small ratio of the traffic volume.

An analysis of streaming traffic was performed, separating households with different broadband access speed. We decided to focus on Flash video, which currently is the dominating application for streaming data, used on, for example, Youtube. The results are shown in Table IX. As can be seen, households

Table VIII  
ANALYSIS OF WWW USAGE

<b>News/Media</b> 5.4%	<b>Multimedia</b> 24%	<b>Social</b> 7.9%	<b>Information</b> 4.4%
<b>Commercial</b> 3.8%	<b>Software</b> 10%	<b>Game</b> 5.6%	<b>Hobbies</b> 1.5%
<b>Adult</b> 2.3%	<b>3rd party</b> 7.5%	<b>WWW</b> 11%	<b>Images</b> 1.1%

with the lowest bandwidth (1/1 Mbps) use less streaming than other households, otherwise, there are no major differences.

Table IX  
FLASH VIDEO (STREAMING)

Access In/Out Mbps	<b>1/1</b>	<b>10/10</b>	<b>100/10</b>	<b>100/100</b>
No. of active households	107	865	96	42
Minutes/day	10	33	35	23
MB/day In	27	93	106	65
MB/day Out	0.6	1.8	1.7	1.0

## VII. USER ACTIVITY MODELLING

A more detailed investigation of the user activity was performed during two weeks. From the measurements, we cannot, and wish not, identify the total activity of a single user. However, it is possible to find the traffic per active IP address (active host) during a certain time interval. Since dynamic IP addresses are used, a single IP address could belong to several users during a longer time period. However, during a short time period, in this case 5 minutes, we assume that the traffic generated by an active IP address corresponds to the activity of one user. The data in this section come from measurements between 2009-05-01 and 2009-05-14.

We have only analyzed *active users*, here defined as an IP address that generates more than 300 kbits (37.5 kB) during the 5-minutes interval. An online computer generates some keep-alive traffic all the time, even if there are no applications running. We have decided to not take the keep-alive traffic into account. A similar approach was used in [13], where an active client was defined as a user that generates at least 100 kB of data during a 30 minutes period. In [4] a time resolution of 2 hours was used, and, therefore, it did not contain a detailed analysis of user activity.

Also, we defined an *active session* as the time period during which one IP address generates more than 1 kbps. We have made the realistic assumption that if one host disconnects from the network during one 5 minute period, and thereby returns its IP-address to DHCP, this IP-address will not be distributed to another host during the same or next 5-minute period. Therefore, an active session represents the time period when at least one application is active on a host computer. Since all our data is averaged over 5 minutes, the length of an active session is a number of such 5 minute periods. In [12], a user session was defined as the time period when one host occupies one IP address, which means that sessions can contain periods with no active applications.

There were 6693 active IP addresses during the time period, with a total of about 2.5 million data samples where the traffic rate was at least 1 kbps.

### A. Traffic rate distribution

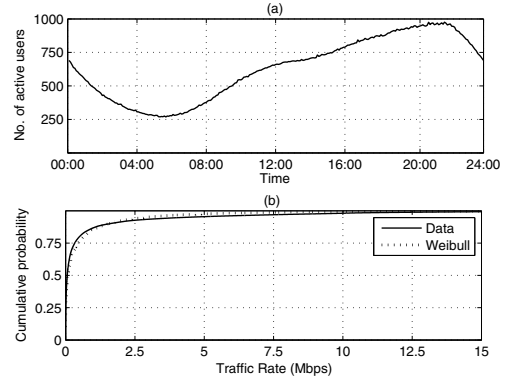


Figure 5. (a) Average number of active users during a day. (b) Cumulative distribution function for traffic rates. The Weibull parameters are  $\lambda = 0.2072$  and  $k = 0.4140$

In Figure 5(a) the average number of active users during a day are shown. As can be seen, there are many active IP addresses also during night, mainly due to file sharing applications. Figure 5(b) shows the cumulative distribution function for the traffic rate per active user. The data samples are averages during the 5 minute measurement intervals. More than 90% of the data points have a traffic rate less than 2.5 Mbps. However, there is a very long tail, and the maximum measured rate was 122 Mbps (the maximum bandwidth was 200Mbps (100/100)). The mean traffic rate was about 850 kbps, whereas the median value was as low as 60 kbps. Earlier measurements, on DSL broadband access, see, for example, [13], showed a traffic rate of below 500 kbps for most users.

In the graph we have fitted the data with a Weibull distribution with a maximum likelihood estimation of the parameters computed using the data samples. The Weibull distribution is used in many areas due to its flexibility. The cumulative distribution function for a Weibull distributed stochastic variable  $X$ ,  $F(x) = P(X \leq x)$ , is given by

$$1 - e^{-(x/\lambda)^k} \quad (1)$$

for  $x > 0$ . The distribution contains two parameters, the shape,  $k > 0$ , and the scale,  $\lambda > 0$ . The fit shown in Figure 5(b) has  $\lambda = 0.2072$  and  $k = 0.4140$ . As can be seen,  $k < 1$ , which indicates a so called decreased failure rate. In our case, this means that there is a high probability for low bit rates, but there are also some data points with very high bit rates.

### B. Active user sessions

Some characteristics of active sessions have also been analyzed. During the two week period, there were 240206 registered active user sessions.

Figure 6 shows the cumulative distribution functions for the active session lengths. There were mainly short sessions, but

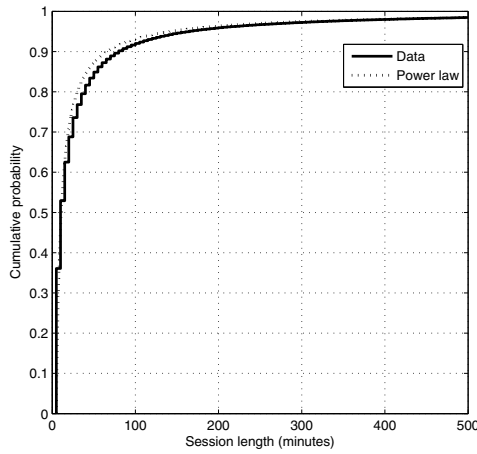


Figure 6. Cumulative distribution functions for the length of an active session. Solid line: Data; Dashed line: Fitted power law distribution with  $x_{min} = 5$  and  $\alpha = 1.9$ .

some of the sessions lasted the whole measurement period (two weeks). The data shown in Figure 6 can be closely fitted to a power law distribution. The probability density function,  $f(x)$ , for a power law distribution is given by

$$f(x) = \frac{\alpha - 1}{x_{min}} \left( \frac{x}{x_{min}} \right)^{-\alpha} \quad (2)$$

where  $\alpha > 1$  and  $x \geq x_{min}$ . In our case,  $x_{min} = 5$  (when counting in minutes) since all data is averaged over 5 minutes intervals. In Figure 6, a fitted power law distribution with  $\alpha = 1.9$  is shown. The parameter  $\alpha$  has been derived with the estimator equation

$$\hat{\alpha} = 1 + n \left[ \sum_{i=1}^n \ln \frac{x_i}{x_{min}} \right]^{-1} \quad (3)$$

where  $x_i$  are the  $n$  data points  $x_i \geq x_{min}$  [22]. One characteristic of the fitted distribution is that all moments are infinite since  $\alpha < 2$ . However, this behavior can be explained in “real life”, since we know that some users have P2P file sharing applications running constantly, and if a longer measurement period would have been used, longer sessions would have been registered. Also, we performed the same detailed analysis on sessions lengths for a two week period in September 2007. The results for that data were almost identical to the results shown in Figure 6, implicating that the model is accurate also in the long term.

The log-normal distribution has since long been known to well characterize connection sizes and durations [23], [24]. In [12] a detailed analysis of residential user sessions was included. In the paper, they also found that the session lengths could be fitted with a log-normal distribution. The same result was derived in [9] where live streaming media sessions were analyzed, as well as in [15]. Our analysis concerns active sessions, during which several connections can be established. The characteristics of active sessions are of course of importance for access network operators, since these represent the

time periods when users generate traffic. To only model user sessions are not enough, since many users today are online constantly. Our investigations showed that the length of an active session cannot be accurately described by a log-normal distribution.

## VIII. EFFECTS OF LEGAL DECISIONS

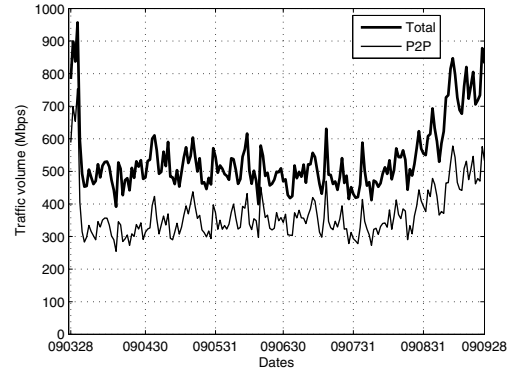


Figure 7. Average traffic volumes per day from 2009-03-28 until 2009-09-28.

The scope of this paper has been to characterize user behavior regarding Internet usage. One aspect regarding Internet usage is its dynamics and sometimes rapid changes, making trend analysis an extremely important research topic. This, however falls outside of the scope of this paper, and will have to be regarded as future work.

One aspect that needs to be mentioned, though, is the change in usage due to the Swedish enforcement of the European Union’s Intellectual Property Rights Enforcement Directive (IPRED). The law, which came into force on 1 April 2009, makes it possible for copyright holders to get a court order requesting ISPs to provide IP addresses associated with computers which have downloaded copyrighted material without paying for it.

Figure 7 shows the traffic volumes from 2009-03-28 until 2009-09-28, measured as an average value per day. Both the total traffic volumes and the P2P file sharing traffic volumes are shown. As can be seen, the traffic volume dropped by approximately 50% on April 1st, mostly due to the drop in file sharing traffic. When looking at the total traffic volume in the end of September, it can be determined that the network has lost roughly the equivalent of one year of traffic volume increase. It is worth noting here that the number of users did not drop in the same dramatic way, but rather by approximately 15-20%.

Another change in user behavior that can be noted is the increased usage of the PPTP protocol since April 1st 2009. The PPTP protocol is used by many anonymization services. From basically not being used at all in the beginning of 2009, the preliminary results show that PPTP is used by 5-10% of the IP addresses at the end of 2009. This may have a significant effect on Internet traffic patterns, since the traffic is forced outside of the operator network, to a third party provider. However,

these results can still be regarded as preliminary, and the data needs further analysis.

## IX. CONCLUSIONS

In this article, we have presented an analysis of traffic measurements from a Swedish municipal network with Fiber-To-The-Home (FTTH). We have presented detailed usage characteristics regarding traffic volumes, applications, and user activity. The measurements were performed with a commercial monitoring tool, Packet Logic, which is used by network operators in many countries. The advantage with this tool is that it can give a very detailed identification and classification of the Internet applications.

Some general conclusions can be made. First, many households generate much file sharing traffic, and more than 70% of the traffic volume is generated by file sharing applications, mainly BitTorrent. The traffic is asymmetric, with more outbound traffic than inbound traffic. This is mainly due to BitTorrent that many users run on their computers all the time.

Other application groups that have been analyzed are web browsing, multimedia streaming, and online gaming. Multimedia sites are generating the most traffic when it comes to web browsing. However, rather much traffic is also generated by news sites, commercial sites, social networks, and gaming sites.

Furthermore, we have characterized households based on their Internet usage. Minutes of use per day for certain applications, number of applications used, penetration of applications as well as volume generated per application was analyzed for households with different broadband subscriptions, ranging from 1 Mb/s to 100 Mb/s. Also, some models for user activity, as session duration, have been derived.

Finally, we showed how legal decisions can affect the Internet usage behavior. In Sweden, the enforcement of IPRED had dramatic effects on the traffic volumes, where the BitTorrent traffic dropped considerably from March 31 until April 1st when the law was enforced. Also, some preliminary results show that the use of anonymization services increase in the network.

## X. ACKNOWLEDGEMENTS

The work has partly been financed by the CELTIC project TRAMMS, with the Swedish Governmental Agency for Innovation Systems (VINNOVA) supporting the Swedish contribution. Maria Kihl is financed in the VINNMER programme at VINNOVA. Andreas Aurelius and Christina Lagerstedt are partly financed by the VINNOVA project Broadband Behavior, and the European Regional Development Fund.

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