A Qualitative Measurement Survey of Popular Internet-based IPTV Systems

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***Abstract*— Television over the Internet (IPTV) is regarded as the killer application for *Next Generation Networks* (NGN). While the ITU is currently moving toward the standardized of IPTV, several existing applications like Joost and Zattoo are currently already providing a large amount of video content to Internet users. In this paper we study some popular video content delivery mechanisms and characterize them by measurements to study the user-perceived *Quality of Experience* (QoE).**

I. Introduction

Television has traditionally been an entirely broadcast-oriented medium. However, nowadays, new technologies delivering packetized digital video data are on the brink of replacing conventional television broadcasts via terrestrial, satellite or cable transmissions. With increasing access bandwidth speeds for end users, the new *Internet-based television* (IPTV) has gained popularity as a means of delivering high-quality video images. One of its main features is its high degree of interactivity. Users are no longer restricted to the broadcast schedules of TV stations, but can choose the program they wish to see on-demand, whenever, wherever, and on whatever device they want (TV, PC, portable player). Additionally, further value-added services are often included, such as chat functions or other feedback mechanisms allowing the viewers to provide ratings or discussion forums on the shows.

The technological advancement in high-speed Internet accesses facilitates such possibilities. Meanwhile, a large coverage of DSL or *fiber-to-the-home* (FTTH) is available and improved video encoders like H.264 permit the transmission of clear high-resolution video images at half the bitrate of MPEG2 current on DVDs.

In addition, offering IPTV has now also become an attractive business model for telecommunication service providers. Many providers no longer limit their offer just on telephone or Internet access, but provide so-called *triple play* services, integrating Internet, *voice-over-IP* (VoIP) telephone services, as well as television or movie channels. Furthermore, it is also appealing to businesses, which can offer personalized advertisements, individually tuned to the TV programs the customer is currently watching or localized to his region of access. However, one problem in IPTV is that content is licensed differently in different regions and therefore some IPTV solutions, e.g. Zattoo (Europe) or Gyao (Japan), limit their access only to IP addresses from those regions.

In this paper we characterize some of the popular existing IPTV solutions by describing their architectures and characterizing their traffic through measurements. We focus on the applications Zattoo, Joost, YouTube, PPLive and OTR, and point out their differences in system architecture and technology. Especially in the case of proprietary systems, measurements at the edge of the network are the only feasible way to evaluate the *Quality of Service/Experience* (QoS/QoE) of an arbitrary user. Nevertheless, it allows us to identify the used protocols and constructed overlay topologies.

This paper is organized as follows. In Section II, we provide an overview over IPTV by classifying the offered services as well as their principle network structures and distribution technologies. This is followed in Section III by a brief summary of existing studies on IPTV. The main contribution of our paper will be in Section IV, where we present our own measurement studies of the five IPTV systems mentioned above from the viewpoint of the end user. Finally, we will conclude this paper with an outlook on future work.

II. Overview of IPTV Types

In the following we will give a broad classification of the most commonly used IPTV architectures and technologies.

A. Classification by Architecture

In general, IPTV network architectures can be categorized in two main classes: centralized and distributed. *Centralized systems* follow the traditional client/server paradigm, where server farms with access queues balance and manage the load among the content servers. Examples of this type of IPTV systems are YouTube and OTR. Here, the client directly connects to the server via HTTP and after a queuing/buffering delay directly streams/downloads the contents from the server.

On the other hand, *distributed systems* are usually based on *peer-to-peer* (P2P) technology, e.g. Zattoo, Joost, PPLive. Each user, i.e., *peer*, also automatically acts as a relay for other peers in the network. This means that while watching a video, the peer provides the already downloaded content to other peers. There are several advantages of using P2P-based content delivery systems, as they react better to sudden bursts in requests arrivals [1]. However, the overlay topology must be dynamically set up first and the network must be adaptive to topology changes due to churn.

B. Classification by Type of Content Distribution

An important distinction of IPTV systems is by their content distribution method: *1)* network-based video recorders, *2)* video-on-demand, and *3)* live TV streaming.

1) Network-based Video Recorders: Network-based video recorders operate basically in the same way as home hard disc video recorders, only that the content is recorded and stored on a remote server. An example for such a service is *OTR* (`http://www.OnlineTVRecorder.com`) in Germany. The live TV program is recorded at the OTR server and registered users can download their previously programmed shows and later view them offline on a PC or handheld device. The content can be either downloaded directly from the main OTR server, from user-created mirror sites, or alternatively via P2P file-sharing networks (eMule or BitTorrent). However, in the case of OTR the majority of clients are using the HTTP-based server download platforms. A performance study with analytical models of OTR can be found in [2].

2) Video-on-Demand (VoD): On the other hand, *Video-on-Demand* permits a user to browse a catalogue of video files and as soon as one is requested its playback is started. Thus, VoD is not restricted to any broadcast schedules, but entirely to the user's demand. Among the available VoD systems, YouTube and Joost enjoy high popularity among Internet users. However, both platforms have an entirely different focus and underlying architecture. On the one hand, *YouTube* (`http://www.youtube.com`) is a centralized video sharing web-site where users can upload, view, and share short video clips. Currently, only user-created content with low resolution images using the H.263 video codec is offered. On the other hand, *Joost* (`http://www.joost.com`) aims at providing licensed, high-quality content using the H.264 video codec. In 2007, Joost entered official licensing agreements with several major distributors for offering content from Warner Music, Paramount Pictures, etc. However, much of the content available on Joost is restricted to users in North America due to international licensing regulations. For delivering their videos, Joost uses P2P technology integrating the end user into the content dissemination process.

3) Live TV Streaming: The third category describes the streaming of live TV channels over the Internet, just as they are being aired over conventional broadcast media. *PPLive* (`http://www.pplive.com`) is a Chinese IPTV application which offers both VoD as well as live TV channels. However, most available programs are in Chinese with a small amount of English content, such as Hollywood movies or popular American TV shows. PPLive is also based on P2P technology. *Zattoo* (`http://www.zattoo.com`) is a pure live TV streaming application in Europe, which is also operating over P2P. At the moment, the service is available only in few European countries, such as Germany, Switzerland, Denmark, Spain, and the UK. Due to licensing restrictions, users are only allowed to watch channels that are offered in their respective countries. This is checked by mapping the IP address of the user's PC to his geographical location.

III. Related Work

We now briefly summarize related work on IPTV, especially P2P-based systems (P2PTV), e.g. PPLive, SOPCast. In [3], network-wide effects of P2P multicast on the video quality delivered to end-users are investigated. They show that P2P over best effort IP networks can not reach the quality of QoS-enabled IP multicast. Although the P2P system is not specified, [3] is the only available study at a P2P multicast provider.

PPLive has been widely studied through measurements [4], [5]. Its protocol, emerging video/control data traffic, and user characteristics are investigated, as well as the topology from the viewpoint of a local peer. Ali *et al.* [6] analyze control traffic based on packet sizes of P2PTV and conclude that the data distribution structure is built randomly without any consideration of bandwidth. In [7] insights about the peer's lifetime and resulting churn in P2PTV during a large-scale event are studied on the edge of the network.

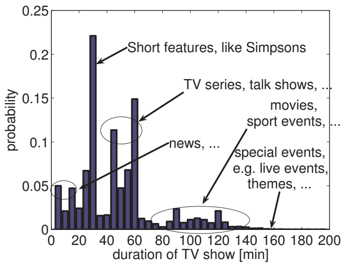
A similar approach is followed in [8], [9] for Joost. Measurements from the edge are performed to identify data and control traffic by packet sizes and used protocols. Both studies focus on the peer selection strategy and can not find any evidence if proximity among peers is taken into account. [8] reveals specific servers in the Joost infrastructure which are used for administration and video content delivery and [9] additionally show results in a wireless LAN environment.

In [10], YouTube videos are evaluated by distinguishing the categories and popularity of video clips, as well as user access patterns like views and ratings. Small-world characteristics for video groups are identified and strategies for utilizing these clustering effects are proposed. Furthermore, [11] monitors YouTube usage in a local campus network in order to understand how it is used by clients. They also provide statistics on the most popular videos at the YouTube site.

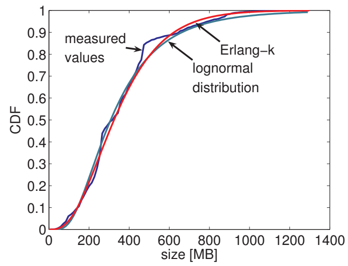
To our best knowledge, no studies exist on Zattoo and OTR except our own previous work in [2]. The intention of this paper is to cover a wide range of popular IPTV video applications. The presented measurements aim at: *a)* a better understanding of the generated traffic and the design of IPTV systems, *b)* a qualitative characterization of the relevant content delivery mechanisms, and *c)* providing statistically significant data for future analytical models where possible.

IV. Measurement Study of IPTV Systems

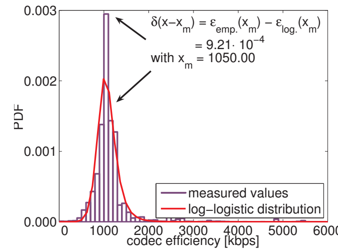
All presented IPTV applications and systems in this work are proprietary. Therefore, each system is regarded as a black box and measurements are taken from the user's edge. For the following experiments, the latest available software release for each application was installed on a PC running a standard installation of Windows XP. The measurement PC was directly connected via a German DSL provider to the Internet with an uplink bandwidth of 800 kbps and a downlink bandwidth of 16,000 kbps. DSL speed tests have shown that during the course of the measurements at least 650 kbps on the uplink and 4,000 kbps on the downlink were available. All measurements took place in December 2007, except for the measurements of the OTR service which were performed in April 2007.



(a) Probability distribution of show durations



(b) CDF of file sizes



(c) Codec efficiency

Fig. 1. Measured TV show durations, file sizes, and codec efficiency of OTR

The aim of these measurements is to characterize the different content delivery mechanisms qualitatively. If possible, extensive measurements are conducted in order to quantify relevant characteristics. A qualitative comparison of the key features of the measurements of the IPTV systems is given in Section IV-C and results are summarized in Tables II and III.

A. *Extensive Measurements for Centralized Systems*

The performance evaluation of a centralized system can be done by means of queuing theory, see [2]. The input parameters are the arrival process, user behavior, number of servers, server discipline, and service time. As we are observing from the edge of the network, among those input parameters only the service time can be obtained, which is in our case characterized by the offered video file sizes. Table I summarizes the statistics of the measurement studies.

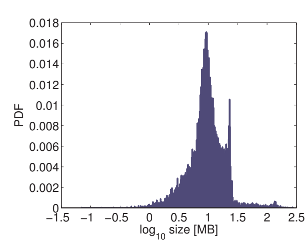
1) Network-based Personal Video Recorder – OTR: We measured the actual file sizes and durations of 11563 random TV shows offered at OTR from 19 different TV channels. Fig. 1(a) shows the probability distribution of the show durations in minutes. The majority of the files (95%) are discretized in units of 5 min. We can distinguish 4 different categories of TV shows. Most files are about 30 min (e.g. animation series) and shorter files may be news programs. Another peak can be found between 45-60 min which is the usual duration of TV dramas or other periodical shows. Movies usually have a duration between 90-120 min and very few larger recordings of special events exist, like the broadcasts of live sports events.

However, we are more interested in the file size distribution than the duration of the shows in order to approximate the download time. Fig. 1(b) shows that the measured file size distribution has a mean of 368.31 MB and standard deviation of 196.82 MB and can be well fitted by a lognormal or an Erlang-k distribution with $k = 3.34$ phases and an average volume of B =107.67 MB per phase. Fig. 1(c) shows the codec efficiency as ratio of the file size over the duration of the TV show in kbps. The probability density function (PDF) has a distinct peak at about 1 Mbps and is comparable to other standard quality video formats, such as VCD or SVCD. The measured values could be well fitted with a log-logistic distribution superimposed with a Dirac function at the peak value x_m. The normalized height added by the Dirac peak is approximately 9.21e-4 and the strong peak is also expressed by the high kurtosis value of 86.05, see Table I. The skewness of 7.33 shows the long tail character of the codec efficiency. For a VoD system, the average achieved bitrate must be larger than the codec efficiency for a smooth video playback.

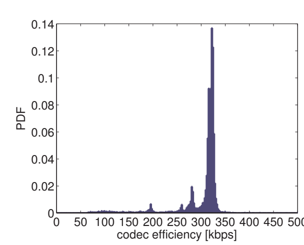
2) Server-based Video-on-Demand – YouTube: We downloaded 21014 randomly selected video streams from the YouTube website and analyzed their file sizes and durations. For the data transport, an HTTP connection to the server is established and the content is delivered via TCP. Currently, YouTube uses the H.263 video codec and the MP3 audio codec, packed into the flash video container (file extension *.flv*). The video bitrate of a random stream is about 300 kbps, while the audio bitrate is about 60 kbps.

Fig. 2(a) shows the PDF of the sizes of downloaded video streams from YouTube. Note that the x-axis is logarithmically scaled, as user-created content is usually restricted to 10 min. With a special user account, however, it is also possible to upload larger video files. In our measurements, we observed video durations of up to 170 min and video sizes of up to 275 MB. Again, the file size distribution is leptokurtic highlighted by the strong peak of the PDF at 22.85 MB. This peak corresponds to the maximum allowed duration of 10 min for user-created contents.

For YouTube videos, the codec efficiency shows a very strong peak at roughly 315 kbps and is nearly constant, see Fig. 2(b). Accordingly, the PDF of the video stream durations looks quite similar to that of the stream size and is omitted here. The negative skewness of the codec efficiency shows that



(a) PDF of video stream sizes



(b) Codec efficiency

Fig. 2. Measurements of YouTube video streams

TABLE I

FILE SIZES, DURATIONS OF TV SHOWS, AND CODEC EFFICIENCY FOR OTR AND YOUTUBE

		mean	std	CoV	skewness	kurtosis	median	min	max
OTR	**duration [min]**	47.21	29.27	0.62	1.14	4.42	45	1	195
11563	**size [MB]**	343.19	186.71	0.54	1.12	4.31	305.87	0.06	1236.87
samples	**efficiency [kbps]**	1155.01	662.93	0.57	7.33	86.05	1038.42	0.71	16310
YouTube	**duration [s]**	339.11	419.16	1.24	7.91	90.64	252	5	10233
21014	**size [MB]**	12.38	14.88	1.20	7.09	69.25	9.41	0.07	274.59
samples	**efficiency [kbps]**	302.11	52.43	0.17	-1.61	16.81	318.54	1.12	1040.52

the mass of the distribution is concentrated on the right of the figure and only a few videos require less bandwidth.

B. Characteristics of P2P-based Systems

The P2P-based IPTV systems which we present in this section are Joost, Zattoo, and PPLive. These proprietary systems have in common that they all integrate the end-user in the content dissemination process. In order to provide an accurate model and evaluation of a P2P system, the applied mechanisms have to be known: *a)* the cooperation strategies determining when and which parts of content are exchanged, *b)* incentive mechanisms to guarantee fairness (like the *tit-for-tat* strategy in BitTorrent or the credit point system in eMule) as well as *c)* the signaling traffic to maintain the overlay, to get information about other peers' locations or capabilities, or to measure overlay links, e.g. round trip times. As a consequence, an overlay topology is formed in a self-organized manner.

As the topology is unknown for these proprietary systems, we consider them as a black boxes and focus on a qualitative characterization of the P2P-based IPTV systems by single measurement traces. The idea is to identify the relevant features of these systems like consumed bandwidth, number of overlay connections, or used transport protocol.

1) High Quality Video-on-Demand System – Joost: In Joost there is an integrated channel explorer for navigating through the list of available channels. Our experiment started with the Paramount Movie Channel and after a short advertisement clip, the video playback of the movie of length 102 min began. Fig. 3(a) shows the bandwidth consumption over time for TCP and UDP in uplink and downlink directions. Time is discretized in intervals of 1 s and the received amount of data during each interval is captured. The header size (including Ethernet, IP, and UDP/TCP) is also taken into account for the bandwidth calculation. We can see that for retrieving signaling data, like exploring the Joost channels, TCP is used. The amount of signaling traffic, however, lies below 10 kbps throughout the entire movie. The video content itself is downloaded via UDP packets with a size about 1100 B and the consumed bandwidth is up to 500 kbps. As the Joost user is participating in a P2P network and provides the already downloaded content to other peers in the network, we observe an upload bandwidth of roughly 70 kbps via UDP.

During the measurements, around 500 different IP addresses were contacted, located mainly in Europe and North America. The results revealed that over 600 UDP connections and around 200 TCP connections were established, see 'Joost Movie' in Tables II and III. The table also contains similar results from a measurement made in Japan labeled 'Joost (Japan)' and a short 2 min clip labeled 'Joost (short)' to see how quickly a new peer is integrated into the overlay. Even in this short time frame, about 140 peers were contacted and the downlink bandwidth consumption was already over 350 kbps. An interesting observation was that during the test run in Japan around 1,400 UDP connections were established, i.e., twice as many as during the test run in Germany.[1] However, in both cases, there were about 500 UDP contacts, i.e., IP addresses with whom several UDP connections were established.

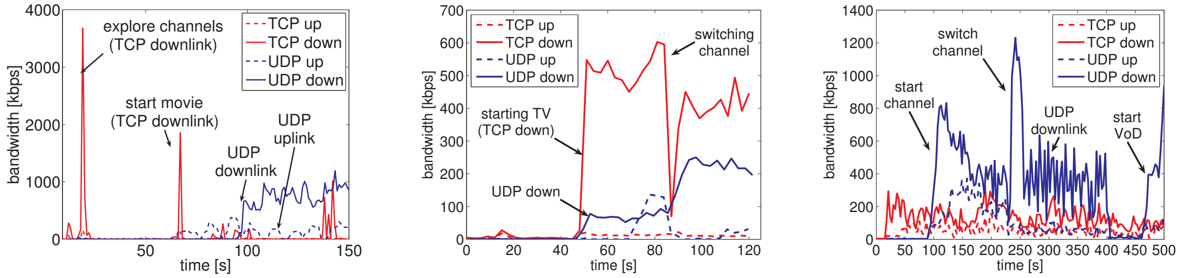
2) European Live TV System – Zattoo: As mentioned above, Zattoo is limited to Europe and therefore the measurements could only be performed on the PC in Germany. Again, we conducted a short run of 2 min (labeled 'Zattoo (short)') and a long run of 87 min (labeled 'Zattoo show'). When selecting a TV channel, Zattoo starts to download video and signaling data via TCP and UDP. Fig. 3(b) shows the consumed bandwidth over time for both protocols in uplink and downlink direction, respectively. The achieved TCP downlink bandwidth is about 500 kbps. After switching to a certain channel, data is first downloaded via UDP, but after a short time no significant amount of data is downloaded anymore via UDP. This results in a UDP downlink bandwidth of 86.82 kbps for the short video and 0.68 kbps for the long video, respectively. Thus, it can be concluded that Zattoo mostly downloads its video content via TCP. UDP is used to exchange signaling information or to construct the overlay topology, which might require delay or bandwidth measurements between the peers.

[1] The reason for this difference could be in the higher bandwidth of the test PC in Japan connected via an optical FTTH link.

TABLE II

MEASURED LENGTH IN [MIN] AND NUMBER OF CONNECTIONS (CNX) AND CONTACTS (CTX) FOR DIFFERENT IPTV SYSTEMS

	length	IP	TCP		UDP	
	[min]	cnx	cnx	ctx	cnx	ctx
Joost (short)	2.34	142	44	6	191	136
Joost Movie	104.14	504	184	11	672	493
Joost (Japan)	30.01	522	129	7	1399	507
Zattoo (short)	2.06	64	36	26	41	41
Zattoo show	87.16	129	280	42	95	91
PPLive (short)	2.12	531	150	90	528	514
PPLive	27.21	4784	1325	850	5256	4756
PPLive (Japan)	30.01	3611	2726	1223	3828	3562
YouTube	7.99	14	20	14	0	0



(a) Joost (b) Zattoo (c) PPLive

Fig. 3. Bandwidth consumption over time during P2PTV measurements

TABLE III
MEASURED BANDWIDTH CONSUMPTION IN [KBPS] FOR DIFFERENT IPTV SYSTEMS

	TCP	UDP	up	down	TCP(up)	TCP(down)	UDP(up)	UDP(down)
Joost (short)	86.12	391.01	91.46	356.14	9.08	77.04	88.99	302.15
Joost Movie	9.85	546.75	69.24	487.08	3.02	6.82	66.32	480.48
Joost (Japan)	9.07	522.78	12.88	516.33	1.06	8.01	11.84	508.77
Zattoo (short)	285.15	104.27	28.68	359.51	11.44	273.71	19.06	86.83
Zattoo show	578.11	92.18	108.85	561.12	17.67	560.44	91.47	0.68
PPLive (short)	209.29	479.17	94.26	582.08	44.68	164.63	50.90	428.44
PPLive	117.95	586.80	196.43	502.29	42.22	75.75	155.82	430.95
PPLive (Japan)	159.73	547.79	196.69	509.95	42.15	117.59	154.58	392.73
YouTube	326.63	0.21	11.19	315.49	11.17	315.47	0.02	0.02

Regarding the overlay topology, Zattoo only contacts 129 IP addresses and 280 TCP connections are established to 42 of these IP addresses (TCP contacts in Table II). To each of the UDP contacts, a single UDP connection is usually established at the same time. When switching between channels in Zattoo, the consumed TCP downlink bandwidth drops to zero for about 2 s and the video playout buffer of 2 s is filled. From switching a channel until the broadcast of the newly selected channel, Zattoo shows a still advertisement image.

3) Chinese VoD and Live TV System - PPLive: Among all the investigated IPTV platforms PPLive shows the highest resource consumption. Independent of live TV or VoD about 500 kbps are measured in downlink direction similar to Joost. However, on the uplink about 200 kbps are used, i.e., nearly double as much as Zattoo and three times as much as Joost. The video is delivered via UDP consuming 80 % of the downlink bandwidth. During the 30 min experiment from Germany and Japan more than 4,000 and 3,000 IP connections were made, respectively. In both cases, peers were contacted worldwide with the majority in China due to the offered content.

Fig. 3(c) shows the bandwidth consumption over time for the PPLive experiment performed in Germany. After 90 s, a live TV channel was selected, indicated by the increase of UDP downlink bandwidth. Switching to a different live TV channel resulted in the peak of 1 Mbps. Stopping the live TV transmission caused the UDP data transmission in both directions to drop to zero. Nevertheless, TCP datagrams were still exchanged. After switching to a VoD channel no differences to the live TV mode could be observed.

C. Comparison of the IPTV Systems

OTR and YouTube are both web-based server-oriented systems. OTR records TV shows at the main server or mirrors, and HTTP or FTP over TCP is used for file transfer. The achieved download speed heavily depends on the selected mirror. For many mirrors, the user's DSL access speed is the limiting factor. However, a user often has to wait for an available download slot until he is served. OTR supports different video resolutions from low quality (160×120) to high quality (720×576) and post-processing of the videos allows e.g. to remove commercials. On the other hand, YouTube is designed for VoD sharing user-created contents and video streams are downloaded over HTTP. Currently, only low resolutions are supported. In most cases, the downlink speed of the VoD server is slightly higher (about 320 kbps) than the maximum video bitrate of 314 kbps, leading to a smooth playback.

For the P2P-based Zattoo, Joost, and PPLive the transport protocols, the bandwidth consumption, and the formed topology are of interest. Joost and PPLive use UDP for delivering the video content with a measured UDP downlink speed over 500 kbps in both cases. In contrast, Zattoo uses TCP for delivering the video content, also requiring over 500 kbps on the downlink. While Joost and Zattoo consume an upload bandwidth between 70-100 kbps, PPLive is the most aggressive in bandwidth demand (about 200 kbps) and number of contacted peers. While Zattoo only contacts about 100 peers and Joost about 500, PPLive connects to several thousands.

The bandwidth consumption of the different applications is visualized as spider plot in Fig. 4. Each measure of interest is shown along an individual axis, indicated by its label and

TABLE IV

QUALITATIVE COMPARISON OF DIFFERENT IPTV SYSTEMS

	OTR	YouTube	Zattoo	Joost	PPLive
service	web-based PVR	VoD	live TV	VoD	live TV/VoD
architecture	central server/mirrors	central server farm	P2P	server-assisted P2P	P2P
connections	unicast	unicast	appl.-layer multicast	$m:n$ unicast	$m:n$ unicast
supposed topology	star	star	tree/forest	mesh	mesh-pull system
commercials	during shows; on web sites	none for user-created content	during shows; while switching	video-specific ads while watching	integrated in application
resolution	512 x 384 (default)	320 x 240	350 x 288	720 x 576 (PAL)	560 x 440
downlink / uplink	up to 1 Mbps / 0 kbps	320 kbps / 0 kbps	560 kbps / 100 kbps	500 kbps / 70 kbps	500 kbps / 200 kbps
TCP / UDP	only TCP	only TCP	580 kbps / 100 kbps	10 kbps / 550 kbps	120 kbps / 590 kbps

maximum value. The corresponding points on all axes are connected for each IPTV application, resulting in a polygon whose shape can be used to classify the IPTV systems. The spider plot reveals that PPLive and Joost show similar characteristics, however, PPLive is more demanding due to its larger polygon area. Zattoo exhibits a completely different behavior, which seems rather comparable to YouTube at first glance. However, the uplink characteristics of Zattoo and YouTube are, of course, of entirely different nature, see the 'uplink' and the 'UDP uplink' axes in Fig. 4.

The geographic locations of the contacted peers are locally confined in Zattoo due to licensing restrictions, but Joost and PPLive establish world-wide connections. The majority of contacted peers in Joost are in Europe and North America, for both experiments conducted in Germany and Japan. However, more Asian peers were contacted when launching Joost in Japan. In PPLive most peers are located in China due to the nature of the offered content. PPLive is the only application which offers both, live TV and VoD, while Zattoo provides only live TV and Joost only VoD. Finally, PPLive and Joost offer nearly TV-like quality, while Zattoo focuses rather on mobile users with low resolutions.

V. CONCLUSION AND OUTLOOK

Our focus in this paper was on how the user perceives the different IPTV platforms. As most networks are proprietary, we could only qualitatively conduct measurements at the network edge, however, from two different regions. The studies provided indications on features of the proprietary systems concerning their topologies, protocols, and bandwidths.

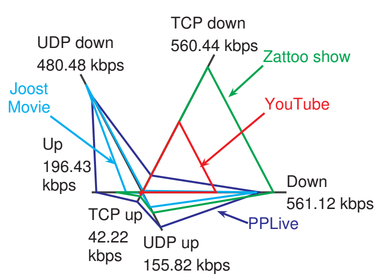


Fig. 4. Spider plot of the bandwidth consumptions of the five investigated IPTV applications

Analytical evaluations can be performed for server-based systems using queuing theoretical methods and taking realistic values as input parameters [2]. On the other hand, when the system structure is unknown, modeling becomes nearly infeasible. One approach is to consider semi-analytical fluid models taking into account the influences from incentives, cooperation strategies, user behavior, etc. on the time-dynamic total system capacity. In the future, we wish to obtain a broader view of an entire P2P network at ISP level, i.e. the dynamic user behavior (churn), system scalability, popularity of files, and inter-domain traffic to provide realistic analytical models.

ACKNOWLEDGEMENTS

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