Influence of Traffic Management Solutions on Quality of Experience for Prevailing Overlay Applications

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***Abstract*—Different sorts of peer-to-peer (P2P) applications emerge every day and they are becoming more and more popular. The performance of such applications may be measured by means of Quality of Experience (QoE) metrics. In this paper, the factors that influence these metrics are surveyed. Moreover, the impact of economic traffic management solutions (e.g., proposed by IETF) on perceived QoE for the dominant overlay applications is assessed. The possible regulatory issues regarding QoE for P2P applications are also mentioned.**

I. Introduction

Content distribution with peer-to-peer (P2P) overlay networks is one of the key applications of the current Internet. The applications range from ordinary file-sharing to more sophisticated video streaming approaches, which are projected to rise even more in popularity. However, these systems create new difficulties for networks and Internet Service Providers (ISPs). Overlay connections used by the P2P applications are up to now generally network agnostic and therefore wasteful with resources [1], [2]. Especially the liberate use of inter-domain connections, i.e., the transit links between ISPs, cause a high cost. Furthermore, connections spanning networks of several providers make end-to-end traffic management and quality of service, needed for specific services like live video streaming difficult. To complicate matters further, P2P overlays do not use one single connection to provide a service, but many at the same time, whereas number and quality of these flows change dynamically with the overlay's topology and population.

In this context, the perceived quality (Quality of Experience, QoE) of Internet applications is the key argument for a user when using such an Internet overlay application. On the other hand, traffic reduction, as well as new service provision to increase customers' fidelity or to provide new business models are the most important issues for ISPs. There are different goals set to the analyzed overlay applications which are selected based on specific demands. In particular, the applications should introduce new service provisioning methods and quality of service, e.g., by rewarding well-behaving peers with higher capacity by means of Next Generation Networks (NGN) capabilities. To ensure the mentioned properties the improvement of ISP networks is needed. For example, installation of specialized servers [3], [4], caches or implementation of NGN capabilities are very helpful.

Currently, the IETF ALTO (Application-Layer Traffic Optimization) Working Group has been established. It also identifies the above mentioned problems and focuses on improving P2P performance and lowering ISP costs [5]. A different solution to the problem described above is Economic Traffic Management (ETM), developed within the SmoothIT FP7 project [6]–[9]. ETM operates under the assumption that all parties involved (ISP, user and, if applicable, overlay provider) will participate voluntarily in a management scheme they all profit from. As a consequence, this scheme has to provide incentives to these players to cooperate, so that in the end, a win-win situation is created. In order to enable QoE management, QoE aware feedback mechanisms have to be introduced and used by providers.

The contribution of the paper is to show the influence of traffic management solutions in P2P networks taking the user perceived quality into account. Section II categorizes QoE influence factors into five different groups and discusses their sensitivity to different operational aspects (like overlay organization or ETM mechanisms) qualitatively. Section III discusses the impact of the influence factors on the QoE quantitatively. The obtained results are based on a user survey and can be used to enhance traffic management solutions. In Section IV traffic management solutions and their impact on the perceived service quality are presented. Regulatory issues and the feasibility of the presented mechanisms are discussed in Section V. Section VI concludes the paper.

II. QoE Influence Factors

Quality of Experience [10] is defined by ITU-T Rec. P.10 as *the overall acceptability of an application or service, as perceived subjectively by the end-user*. The subjective perception of the quality depends on several factors, a set of which may be different for various types of applications and services. The QoE influence factors relevant for streaming applications (live and video on demand) are more tangible than for file-sharing. However, some features typical for file-sharing that determine user satisfaction with using the service, can be found. Some of them are applicable also for video streaming applications.

Overall, the five groups of factors can be found, namely related to *lookup*, *downloading*, and *streaming* functionalities as well as *client software operation* and *psychological aspects* like memory effects [11]. Two first of them are related to basic technical functionality of each P2P application, while the third one is relevant only for video applications. The fourth one is also technical, but not necessarily related to the overlay network concept. Last but not least, the fifth one discusses psychological aspects including liability issues.

A. Lookup Functionality

A user profits from the applications after locating peers storing the interesting contents. Three factors are relevant here: (1) **Lookup time**: users become impatient when they perceive a searching procedure as too long. (2) **Relevance ratio**: determines the utility of the overlay application (whether the content is what was expected). It happens that the content is corrupted/infected, of a bad sound/video quality, faked (e.g., pornographic movie instead of a family series episode), or encrypted. This factor can be assessed by a relative occurrence of such surprises. In contrast to file-sharing, the video streaming users can decide very fast if they want to consume the stream or not. (3) **Content availability**: informs on how easy it is to download the desired content when it was found or reflects if a certain video can be streamed to the user. This factor is influenced by the relevance ratio but also by the content lifetime and the type of an overlay.

B. Downloading Functionality

Finding content is half of a success. Then, the user needs to obtain it. Three main metrics can be found here: (1) **Completion time**: strongly related to the mean download speed and the size of the downloaded file. However, the speed is quite a technical notion and is not necessarily clear for all users. They usually assess it in general relation to a class of file size (e.g., a movie or a song). (2) **Fluctuations of downloading speed**: gives the information of how the downloading proceeds. It can have some tranquilizing or annoying influence (suggesting instability, intensive turns off, congestions). It is of a rather short term character, related to a specific file or daytime. (3) **Probability of unsuccessful download**: assessed on a large time scale as a general QoE factor. Even if downloading lasts long, but finishes successfully, users accept it. Contrary, when a user finds information and then is not able to download it, the impression of being cheated by an overlay might appear.

C. Streaming Functionality

The typical factors influencing QoE related to video streaming are different with the ones found for file-sharing. They are given below: (1) **Streaming warm up time**: users become impatient if the stream needs too much time until it starts. (2) **Switching time**: determines the time until the stream can be watched again after switching between channels (in case of live TV) or jumping within a video clip. This includes the warm up time. (3) **Stalling time**: describes the duration when a video is freezed due to the unavailability of the currently required video content at the destination. Stalling may appear for TCP streaming (a video buffer runs empty) or UDP streaming. (4) **Video distortion**: in case of UDP based streaming, the video quality can be disordered if packet loss occurs. This is typically perceived as blur, blockiness, jerkiness and color or luminance distortion. Users tend to have as less stalling or video distortion as possible.

D. Client Software Operation

What people are directly using is not the overlay network itself, but a specific application on a selected PC. Apart from assessing the main overlay functionality, the users tend to assess the overall comfort. Here, two groups of factors can be found: (1) **Overlay client application**: **application warm up time** (including bootstrapping, logging, pre-processing of shared content) or **usage of network bandwidth** (resulting from the burden of overlay signaling or upload). (2) **General usability**: high-level assessment of a software application, like usage of CPU/RAM, disk space, availability for Windows/Linux/Mac, GUI or command line, level of configurability etc.

E. Psychological Aspects

Despite being not technical and difficult to quantify, this group of factors can be strictly related to networking conditions of the overlay. Here, we can find (1) **comfort of anonymity** and (2) **the necessity to share files**. File-sharing popularity stems from the illegal free access to copyrighted content and people would like to avoid a possible liability related to it. The comfort of anonymity is usually only virtual, but the lack of official registration/logging or awareness of some encryption usage can be important. On the other hand, due to some law systems, it is possible that downloading of copyrighted content is legal, but sharing is not. Thus, some users try to be free-riders. There are also other psychological aspects related to QoE, like emotions, feelings, expectations, etc., but they are not discussed, since they can hardly be influenced by traffic management schemes.

F. Sensitivity of QoE Factors to Different Operational Aspects

Table I presents how overlay organization (structure of the overlay network, P2P protocol, general requirements put on a client, etc.) or current state of the overlay (e.g., the current content distribution, the number of online users and their behavior), QoS in an underlay network, and ETM mechanisms can influence the factors related to the assessment of perceived quality of P2P applications. The assessment given within is of a qualitative character.

Impact of intrinsic QoS on different QoE factors is diverse. It is typical for overlay networks that some of them are not dependent on underlying network, but rather hinge on user behavior (e.g., what files are injected to the overlay) or on the general concept of the application. Obviously, QoS has a high impact on factors that are a function of the current throughput (e.g., download completion time, playback continuity, video distortions). Under certain conditions the maximum achievable QoE may be limited by QoS, e.g., by the available link

TABLE I: Qualitative assessment of different aspects influence on QoE factors relevant for P2P applications

Aspect	QoE influence factor	Overlay organization	Current state	QoS in network	ETM influence
Lookup	Lookup time	L	Mo	Mi	Mo
	Relevance ratio	L	L	N	N
	Content availability	Mo	L	Mi	Mo
Download	Completion time	Mo	L	L	L
	Fluctuations of downloading speed	L	L	L	L
	Probability of unsuccessful download	L	L	Mi	Mo
Streaming	Streaming warm up time	L	L	Mi	Mo
	Switching time	L	L	Mi	Mo
	Stalling time	L	L	L	Mo
	Video distortion	Mo	L	L	Mo
Software	Application warm up time	L	Mo	N	Mo
	Bandwidth usage	Mo	L	Mo	Mo-L
	General usability	Mo	Mi	Mi	Mi
Psy.	Anonymity	L	N	N	Mo
	Sharing necessity	L	Mi	N	N

L: large, Mo: moderate, Mi: minimal, N: none.

capacity, packet loss ratio or delay. Bottlenecks may appear at various points of the network, especially in heterogeneous environments.

Videos may be streamed to mobile devices via UMTS, a laptop in a WLAN or an LCD TV with a broadband access. Each of these users has different requirements to the quality of the video stream. Thus, there is no single ideal video stream solution, and the quality has to be adapted with respect to the user's device. Possible solutions are discussed below in detail. Large packet loss ratio may significantly deteriorate the performance of video streaming applications (even if available bandwidth is sufficient for requirements of an application) while it is not so critical for file download performance. Furthermore, small delays enable fast switching between different available TV channels or jumps within a video clip.

ETM mechanisms operate under the assumption that all parties involved (ISP, end-user, and, if applicable, overlay provider) will participate voluntarily in a management scheme they all profit from. Thus, ISPs aim at reducing costs in terms of inter-domain (or inter-AS, Autonomous System) traffic and end-users are interested in a high QoE. The ETM solutions may directly impact the overlay organization by providing proximity awareness or introducing caches and thus enhancing the user's QoE. Additionally, required resources can be adapted to the current network state, the overall QoS enhanced and bottlenecks avoided. Last but not least the negative influence of QoS can be decreased by suggesting peers with better quality connections. It has to be noted, that all of these mechanisms require registration mechanisms that disturb anonymity.

In Section IV, we will illustrate the influence of exemplary ETM solutions on the main QoE influence factors. In particular, the considered ETM solutions change (a) the overlay organization by taking into account network proximity, see Section IV-A; (b) the current state by increasing the available upload capacity via caches, see Section IV-B; (c) the QoS in the network inherently by optimizing the required network resources and thereby the perceived QoE, see Section IV-C.

TABLE II: Results of the user survey: the importance of QoE influence factors

QoE influence factor	Average mark	Median
Lookup time	5.91	6
Relevance ratio	7.71	8
Content availability	7.95	8.5
Completion time	7.96	9
Probability of unsuccessful file download	7.7	8
Comfort of anonymity	6.25	7
Sharing necessity	5.05	5

III. End-user Sensitivity to QoE Influence Factors

In the case of streaming applications the most important factors influencing perceived quality assessment are those directly related to comfort of watching movies, e.g., video distortions, playback stalling frequency and duration, etc. Assurance of continuous playback without image distortions is a necessary condition for high assessment of perceived quality. The continuous playback is especially important for live TV applications since video stalling for several seconds may result in losing some portion of information. Other QoE influence factors related to streaming are less significant but cannot be neglected.

QoE related to file-sharing is less tangible than for video applications. However, it is important to know which of the QoE influence factors are perceived by users as most important or less significant. To assess the sensitivity of file-sharing users to various QoE influence factors, a survey was conducted on a group of over 200 students from Poland. The users were asked which of the QoE influence factors are more important for them while subjectively assessing an application or comparing features of various applications. They rated QoE influence factors using a scale from 0 (insignificant) to 10 (very important). The results are presented in Table II. Five factors received approximately the same average mark but the content availability and completion time appear to be most important.

Additionally, one of the most important perceivable quality factors for users is the relevance ratio. On the other hand, users' demands on this factor are not high. The minimum acceptable value is, on average, 52.3%. If a paid service with improved quality was offered, users would require relevance ratio to be at least 83%, approximately. User expectations related to content availability are similar to the relevance ratio. On average, the minimum acceptable values reported for free and paid premium service are 54.2% and 95%, respectively.

The most meaningful factor for P2P users is a completion time. If a large file is downloaded (e.g., a movie file of 500 MB, or software package of 2 GB), users are likely to

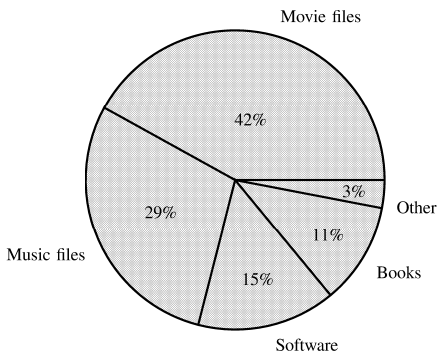


Fig. 1: The distribution of the type of content downloaded by file-sharing applications users due to the survey research.

tolerate a completion time of several hours. Smaller files (e.g., a single music file or a book) are often desired to be downloaded quickly since users want to use them immediately. Users more easily notice and get annoyed at, e.g., 20% longer completion time for small files than for downloads normally lasting several hours. Therefore, the sensitivity of users to this QoE influence factor depends on the type of downloaded content.

The most popular content downloaded by users, i.e. 41.5%, are movie files that are usually of the order of hundreds of megabytes (Fig. 1). The category ‘music’ encompasses complete albums (large files) as well as individual tracks (relatively small files). The similar situation is for software, were large and small packages are possible. Thus, large file downloads are dominating.

According to the ranking (Table II), the comfort of anonymity appears surprisingly to be a less important QoE factor for users. However, a direct question revealed that most of users prefer to be anonymous. Majority of them (75%) prefer services not requiring registration and providing anonymity.

Additionally, people would not like to reveal their preferences, interests and activity. Therefore, ETM solutions are desired to preserve the level of user anonymity offered by an application.

About 61% of the users are reluctant to share files. They usually join an overlay to download a file and disconnect immediately after completing. 19% of users declared to share files and own resources if necessary, e.g., if an application ranks users due to the sharing ratio. Only 20% of users have no objection to sharing files. These results may be biased by the fact that in Poland downloading of copyrighted content for short and private use is legal, but sharing is penalized.

If an operator would like to implement a solution influencing the performance of a P2P application and encourage users to cooperate, it is necessary at least to ensure that the completion time will be perceived as lower while other QoE influence factors do not worsen. Providing paid premium services would be a challenge since user requirements on content availability and relevance ratio would be significantly higher. Unfortunately, those factors are highly dependent on user behavior, a P2P application organization as well as content popularity, but they are difficult to be improved by ETM solutions.

IV. Impact of Traffic Management Solutions on QoE

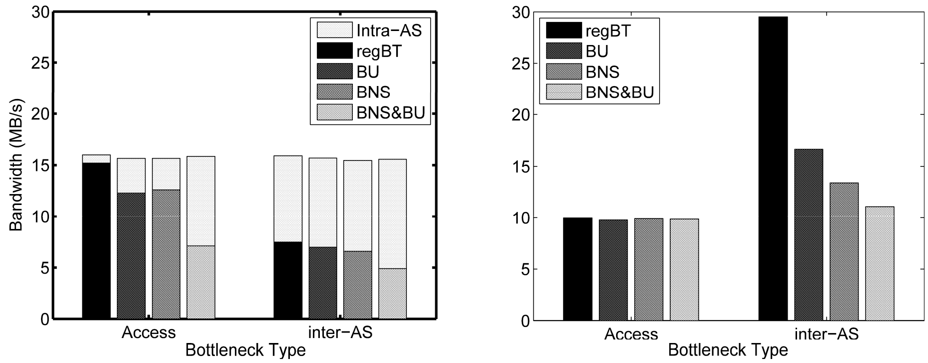
This section presents three different ETM solutions and their impact on the user perceived service quality. ETM operates under the assumption that all parties involved (ISP, end-user, and, if applicable, overlay provider) will participate voluntarily in a management scheme and take advantage from it. As a consequence, this scheme has to provide incentives to these players to cooperate, so that in the end, a win-win situation is created. While the ISP aims at reducing costs in terms of inter-AS traffic, the end-user is interested in a high QoE. As discussed in the previous section, the QoE influence factor most meaningful to file-sharing users is completion time which is considered in Section IV-A and Section IV-B for the BitTorrent file-sharing application.

In turn, the overall QoE of video applications is usually expressed by Mean Opinion Score (MOS). There are two basic methods to evaluate QoE: subjective tests, in which real people assess the perceived quality of the video, and objective methods that use certain algorithms and formulas created to measure the quality. The former provide the best outcome but are costly and time consuming. The most popular and giving fast approximation of QoE objective methods compare quality of received and source streams (full reference metrics). They output MOS or another value that can be mapped to MOS. Such metrics most often take into account video distortions, e.g., SSIM (Structural Similarity Index) [12] that analyses a degradation of a structural information. Some metrics evaluate impact of other QoE influence factors such as streaming warm-up time or playback stalling, e.g., PEVQ (Perceptual Evaluation of Video Quality). Section IV-C shows the influence of an ETM solution for video streaming on the QoE in terms of SSIM.

A. File-Sharing: Changing the Overlay Organization by Taking into Account the Network Topology

The main idea of locality-promotion ETM approaches is to overcome the information asymmetry between the overlay topology and the underlying physical network infrastructure in order to keep the traffic in the same ASes, instead of having long connections spanning several networks. In particular, the ISPs provide information about the network topology to the overlay application, e.g., which peers reside in the same AS and which not. The peers use this information and communicate preferentially with peers in the same AS. The exchange of such information can be realized with dedicated ETM servers or modified BitTorrent trackers, see [7].

The primary strategy recently investigated for the BitTorrent file-sharing application in the literature is Biased Neighbor Selection (BNS) which is complemented by the concept of Biased Unchoking (BU). BNS tries to influence of the composition of a peer’s neighbors in the overlay, since a BitTorrent peer exchanges data with some of its overlay neighbors. In BitTorrent, a peer contacts the tracker to retrieve overlay



(a) Mean inter-AS traffic

(b) Mean download completion times

Fig. 2: Comparison of different locality-promotion ETM approaches for BitTorrent file-sharing networks in terms of inter-AS traffic and download times. Two basic network configurations were tested: with and without inter-AS bottleneck links, see [7].

neighbors. With BNS, the BitTorrent tracker tries to include a certain fraction of local peers in the response. If the swarm does not contain sufficient peers in the AS, the tracker fills the response with other peers to avoid a degeneration of the connectivity of the overlay. With BU, a peer preferentially exchanges data with neighbors which are in the same AS. In particular, BitTorrent's choking algorithm selects the neighbors to which a peer allocates its upload capacity. Due to the implemented tit-for-tat strategy in BitTorrent, it is expected that the peer will benefit by downloading from local peers. Both locality-promotion concepts, BNS and BU, are explained in detail in [7].

Fig. 2 compares the different possible traffic management schemes, (a) BU, (b) BNS, and (c) the combination of BU and BNS with regular BitTorrent (labeled as 'regBT'). A set of simulation experiments were performed for various network configurations [7]. A characterization of BitTorrent swarms and their distribution in the Internet is shown in [13]. Two basic network configurations were tested: with and without a bottleneck on inter-AS links. All locality-promotion mechanisms achieve an inter-AS traffic reduction for both scenarios, see Fig. 2(a). However, the influence on the user perceived QoE is different. Download times remain at the same level when the bandwidth of inter-AS links is unlimited (Fig. 2(b)). Thus, ISP benefits from inter-AS traffic decrease without improving or deteriorating the user perceived application performance. In the case of a bottleneck both parties benefit.

B. File-Sharing: Impact of P2P Caches Operated by ISPs

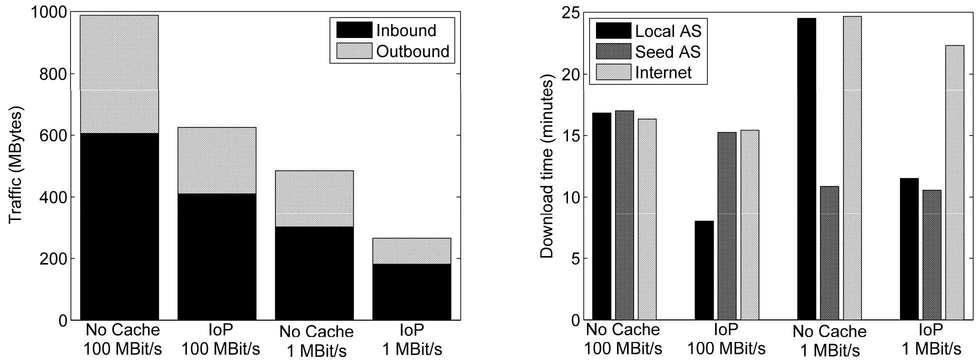
Another example of an ETM solutions are P2P caches that ISP deploys in its own AS. A cache, also called ISP-owned peer (IoP), participates in the file-sharing overlay as a regular peer, but has a significantly large upload capacity. However, in order to utilize the increased upload capacity more efficiently, i.e. to save inter-domain traffic, the file-sharing client of IoP has to be modified, so as local peers are preferred.

The impact of the deployment of an IoP on the download completion time and the inter-AS traffic is depicted in Fig. 3. The results were obtained in a testbed network constructed in the laboratory [14]. The testbed network consists of three ASes, a 'local AS,' a 'seed AS' and the third AS emulating the Internet. The IoP was placed in the local AS and served only peers within this AS. A seed, that initially shares the file for the entire overlay network was located in the seed AS. We tested two scenarios, without inter-AS bottleneck and with bottlenecks of 1 Mbit/s. Fig. 3(b) shows that deployment of IoP decreases the completion time in all ASes, most significantly in a local AS. The introduction of the IoP results further in a decrease of inbound and outbound traffic of the local AS (Fig. 3(a)). Thus, cache-based traffic management schemes are solutions promising to improve the QoE of an end-user while reducing the inter-domain traffic.

C. Video-Streaming: Using SVC for Managing the Required Resource Consumption and the Resulting QoE

By using ETM mechanisms for video streaming, the provider has to take care of the user perceived video quality [15]. It has to be able to estimate how it is influenced by development of the ETM mechanisms. The offered quality has to satisfy the user, but, on the other hand, a high quality content may not be displayed with the provided quality on the user equipment, resulting in a waste of network resources. Thus, a content provider has to offer the same video clip with different levels of quality adapted to the capabilities of the user device. Efficient state-of-the-art solutions providing different qualities within a single video stream are Multi Description Coding (MDC) or Scalable Video Coding (SVC) [16]. While MDC only allows a seamless switching between different Signal-to-Noise Ratio (SNR) quality levels, SVC enables also switching between different frame rates or resolutions within the video stream. Since SVC provides more possibilities to control the user perceived quality and therefore also the required bandwidth, we focus on this approach in the following.

In this context, the question arises how the end-user perceives the actual quality of the delivered video, i.e., is he or she more satisfied with (i) a low resolution, but a smooth video play out, or (ii) a high resolution possibly at the cost of transient quality degradations.



(a) Mean inter-AS traffic of local AS

(b) Mean download completion times

Fig. 3: Influence of caching ETM solution (labeled as ‘IoP’) from the ISP’s point of view in terms and from the user’s point of view. Two different network topologies are considered, with and without inter-AS bottleneck, see [14].

To estimate the QoE, models which allow an approximation of QoE based on QoS and content type, are needed. Due to limited network resources it may not always be possible to provide the video content with the best available quality. Thus, the provider has to decide whether:

- a video stream could be delivered using less resources with equal QoE, or
- the QoE could be enhanced significantly by providing more resources.

An example of the trade-off between QoE and QoS with respect to available bandwidth is given in Fig. 4. We assume that a high quality video content is available with a resolution of 1216×684 pixels and it is played back on an appropriate display in the full screen mode. We investigate the video distortion due to lossy upscaling of video content in less resolution than the full screen by the corresponding player. For that we use a full reference model, that is the SSIM index, and compare the distorted video clip with the original one. A complete description of the experiments can be found in [17].

The average bandwidth requirements for different video clips are depicted in Fig. 4(a). On the x-axis different resolutions are displayed, whereas the scale of the axis is proportional to the number of pixels of each resolution. The y-axis shows the average bandwidth of the video sequence in Mbyte/sec. We observe that there is a strong influence of the content on the required average bandwidth. Furthermore, it can be seen that, regardless of the content type, huge bandwidth savings can be achieved by lower resolutions.

The influence of lower resolutions on the user perceived quality is depicted in Fig. 4(b) for the objective quality estimator SSIM. The x-axis is arranged as in Fig. 4(a), the y-axis denotes the values of the SSIM index. It can be seen that, regardless of the content, a decrease of the resolution yields in a decrease of the SSIM metric. Nevertheless, an SSIM value of 0.95, which indicates still a good quality, is achieved by clips with a resolution larger than 60% than the original video clip.

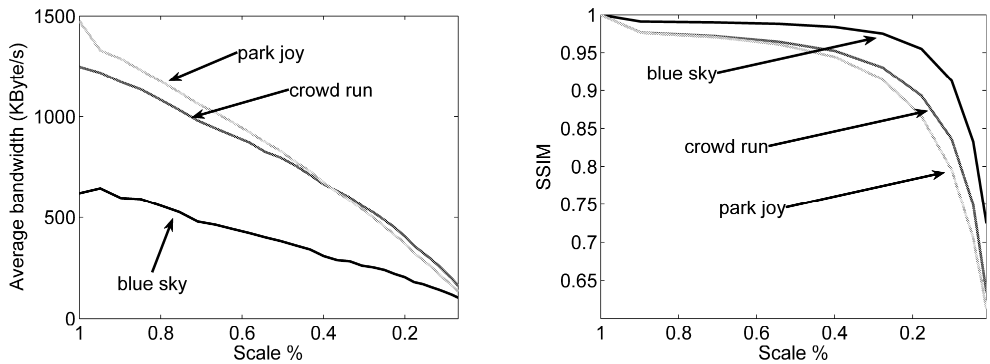
Thus, we can conclude that huge bandwidth savings can be achieved by reducing the resolution and therefore the required bandwidth of the video stream, without a significant impact on the user perceived quality. This result can be used to optimize the user perceived quality by avoiding packet loss due to congestion in the network or long stalling times by insufficient available bandwidth.

V. Regulatory Issues Influence on QoE

QoE is all about the end-user perception, usually subjective. There are many factors which contribute to better or worse QoE. Considering overlay related applications, there are emerging approaches to optimize performance of the overlay network transmissions, e.g., ALTO group or the European project SmoothIT. These solutions aim at improving the overlay networks in a way which would be beneficial for both the operators and the end-users. Obviously, a better working application contributes to higher level of perceived QoE.

Unfortunately, due to possible lawful regulations [2], some of the proposed methods may not be legitimate. Over the past few years the, so called, network neutrality (or net neutrality) debate has attracted a lot of attention, mainly in the US. Most people believe that the Internet should be neutral, however, the exact definition of neutrality differs. The most orthodox views want to prohibit the network operators from tampering with the traffic they carry, explaining that carriers should provide the ‘dumb pipes’ and not care what is inside. More reasonable net neutrality proponents notice the need for traffic management and acknowledge it, as long as it is fair for all the users. In other words, the service differentiation is considered as possible, however, it should be service-based, and not end-user or application based. Obviously, telecom operators do not wish any more regulations to be enforced upon them.

If successful, net neutrality regulations may disallow certain mechanisms which can, otherwise, improve the perceived QoE. Introducing cashes or ISP-owned peers into the network to promote locality is an option totally alongside net neutrality. Ideas, such as highly active peer or NGN based QoS provisioning are not. The former considers enhancing access bandwidths for well-behaving (from the operator’s point of view) peers, which, of course, does not advocate fairness. Similarly, the latter which applies better QoS for certain connections is easily to be seen as unfair. Albeit the rest of the overlay



(a) Required bandwidth for different video clips

(b) Results for the QoE indicator SSIM

Fig. 4: Trade-off between required bandwidth and QoE indicator SSIM for various types of video streaming contents [17].

population does not suffer, the QoS provisioning only for the limited number of users is against the, even reasonable side, of network neutrality.

Although not directly, regulatory issues may impact the development and performance of overlay applications. It is extremely difficult to predict the outcome of the net neutrality debate all over the world, nonetheless, it is believed to play some role in the future. Being unaware of this fact or depreciating its significance, most of the application developers do not take it into account. Analogously, QoE models do not consider the regulatory impact on the perceived quality. Perhaps it is time to adjust the assumptions and tune the models to recognize the problem.

VI. Conclusions

In this paper we investigated the influence of traffic management solutions on the Quality of Experience (QoE) for the prevailing overlay applications file-sharing and video streaming. To estimate quantitatively the significance of the different influence factors on the QoE, a user survey was conducted for the case of file-sharing. It turned out that completion time or successful download have a severe impact on the user perceived service quality which can be influenced by existing traffic management approaches like ALTO and ETM. Thus, the huge amount of expensive and unnecessary inter-domain traffic could be avoided being an important factor for providers to support such approaches. On the other hand, these mechanisms have to provide equal or better QoE in order to be accepted by the users of such applications or services. For the BitTorrent file-sharing application, it was shown that either locality-promotion mechanisms or P2P caching solutions can be used to reduce the inter-domain traffic while enhancing the user perceived quality. Moreover, we investigated a more sophisticated use-case, P2P video streaming and described how improvements of the QoE can be achieved while simultaneously reducing the consumption of costly network resources.

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References

[1] I. Rimac *et al.*, “A Survey on Research on the Application-Layer Traffic Optimization (ALTO) Problem,” IETF RFC 6029, Oct. 2010.

[2] G. Dán *et al.*, “Interaction Patterns between P2P Content Distribution Systems and ISPs,” *IEEE Commun. Mag.*, vol. 49, no. 5, May 2011.

[3] V. Aggarwal and A. Feldmann, “Locality-Aware P2P Query Search with ISP Collaboration,” *Netw. Heterog. Media*, vol. 3, no. 2, Jun. 2008.

[4] H. Xie *et al.*, “P4P: Provider Portal for Applications,” in *Proc. 2008*, Seattle, WA, Aug. 2008.

[5] J. Seedorf *et al.*, “Traffic Localization for P2P-Applications: The ALTO Approach,” in *Proc. P2P 2009*, Seattle, WA, Sep. 2009.

[6] T. Hoßfeld *et al.*, “An Economic Traffic Management Approach to Enable the TripleWin for Users, ISPs, and Overlay Providers,” in *Proc. Future Internet Conference*, May 2009.

[7] S. Oechsner *et al.*, “Pushing the Performance of Biased Neighbor Selection through Biased Unchoking,” in *Proc. IEEE P2P 2009*, Seattle, WA, Sep. 2009.

[8] Z. Duliński *et al.*, “Optimal Choice of Peers based on BGP Information,” in *Proc. ICC 2010*, Cape Town, South Africa, May 2010.

[9] B. Stiller *et al.*, *Incentives, Overlays, and Economic Traffic Control*. Proc. of the Third Workshop on Economic Traffic Management (ETM 2010), Amsterdam, The Netherlands: Springer, Sep. 2010.

[10] R. Stankiewicz *et al.*, “QoX: What is It Really?” *IEEE Commun. Mag.*, vol. 42, no. 4, Apr. 2011.

[11] T. Hoßfeld *et al.*, “The Memory Effect and Its Implications on Web QoE Modeling,” in *Proc. ITC 2011 to be published*, San Francisco, USA, Sep. 2010.

[12] Z. Wang *et al.*, “Image Quality Assessment: from Error Visibility to Structural Similarity,” *IEEE Trans. Image Processing*, vol. 13, no. 4, 2004.

[13] T. Hoßfeld *et al.*, “Characterization of BitTorrent Swarms and their Distribution in the Internet,” *Computer Networks, http://dx.doi.org/10.1016/j.comnet.2010.11.011*, vol. 55(5), Apr. 2011.

[14] P. Chołda *et al.*, “Performance Evaluation of P2P Caches: Flash-Crowd Case,” in *Proc. ATNAC 2010*, Auckland, New Zealand, Oct. 2010.

[15] T. Hoßfeld *et al.*, “The QoE Provisioning-Delivery-Hysteresis and Its Importance for Service Provisioning in the Future Internet ,” in *Proc. of the 7th Conference on Next Generation Internet Networks (NGI)*, Kaiserslautern, Germany, Jul. 2011.

[16] J. Chakareski *et al.*, “Layered coding vs. multiple descriptions for video streaming over multiple paths,” *Multimedia Syst.*, vol. 10, no. 4, 2005.

[17] T. Zinner *et al.*, “Towards QoE Management for Scalable Video Streaming,” in *Proc. ITC-SS21*, Miyazawa, Japan, Mar. 2010.