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ABSTRACT

In this paper, we discuss research problems for enabling content distribution and supporting real-time interpersonal communication services (e.g. voice and video) over best effort networks with sufficient quality. We take a practical view of content distribution and quality, and this is the reason for the term "sufficient". We argue that the understanding of quality as perceived by the user is a key factor in this context, but also that the understanding of context dependence is a key factor for delivering services which are "good enough" to make the user satisfied. We base our assumptions upon results from the Celtic TRAMMS project, and we describe how to leverage upon the framework for traffic measurements that was built up in that project. Moreover, we identify key technological components that are common for optimization of content delivery and real-time interpersonal communication services such as VoIP and videoconferencing. We also describe how the research problems stated will be tackled in the newly started IPNQSIS project.

Keywords: Network monitoring, traffic measurements, QoE, quality of experience, content distribution,

1. INTRODUCTION

Internet usage is evolving from the traditional WWW usage (i.e. downloading web pages) to triple-play usage, where households may have all their communication services (telephony, data, TV) through their broadband access connection. The challenge then becomes to design the networks so that they can deliver services requiring strict QoS demands, such as IPTV, and at the same time provide capacity for unpaid traffic (from the operator's perspective), for example file sharing. New architectures, such as content distribution networks (CDNs), need to be developed in order to provide sufficient quality of future advanced Internet applications.

One key to the success of the future Internet is to determine and understand Internet usage. In the Celtic project TRAMMS [1] (Traffic Measurements and Models in Multi Service Networks), a framework for traffic measurements was created that allowed traffic measurements in broadband access networks. The measurements were performed on the application level, mainly with the PacketLogic (PL) [2] traffic management device. The purpose of the measurements was to build models of IP traffic and user behaviour, see e.g. [3][4]. Data from the application to the packet level per household were collected in real networks located in different countries (Sweden and Spain) covering different types of access (FTTH, xDSL, CMTS, cellular, university network). Measurements from a large amount of users were gathered for long periods of time (close to 3000 TiB of traffic volume was analysed in Spanish and Swedish networks in 2007-2009 in periods ranging from several days to several years). A common methodology was established between the different partners in order to perform and share the measurements with other partners, as well as to prepare them for a later analysis, while preserving the user privacy and respecting the privacy policies and commercial secrets of the operators.

The new Celtic project IPNQSIS (IP Network Monitoring for Quality of Service Intelligent Support) is partly based on results and partners from the TRAMMS project. However, IPNQSIS has a larger consortium and focuses even more on the perspective of the end user. An important novelty of IPNQSIS is that QoE will be used as the main driver for building a complete Customer Experience Management System (CEMS). An overview of the CEMS can be seen in Fig. 1. The QoE input will come from multi-technology network devices (i.e. mainly probes) that will be developed and evaluated in the project. Deep packet and deep flow inspection techniques will be applied to monitor and analyze IP traffic in access networks in order to propose new techniques for distribution of multimedia content while maintaining acceptable levels of QoE. Algorithms and measurements devices will be developed and tested to provide feedback to the control system. Furthermore, cognitive software will be developed to combine QoE-QoS correlation analysis with network operation and traffic modelling studies. All these elements constitute the Customer Experience Management (CEM) that is the main outcome of this project.

In this paper, we elaborate the traffic and network analysis parts of the project and describe the coupling to the QoE modelling activities. We also discuss how the proposed CEMS approach can improve the efficiency and quality of content distribution networks as well as interpersonal communication services.
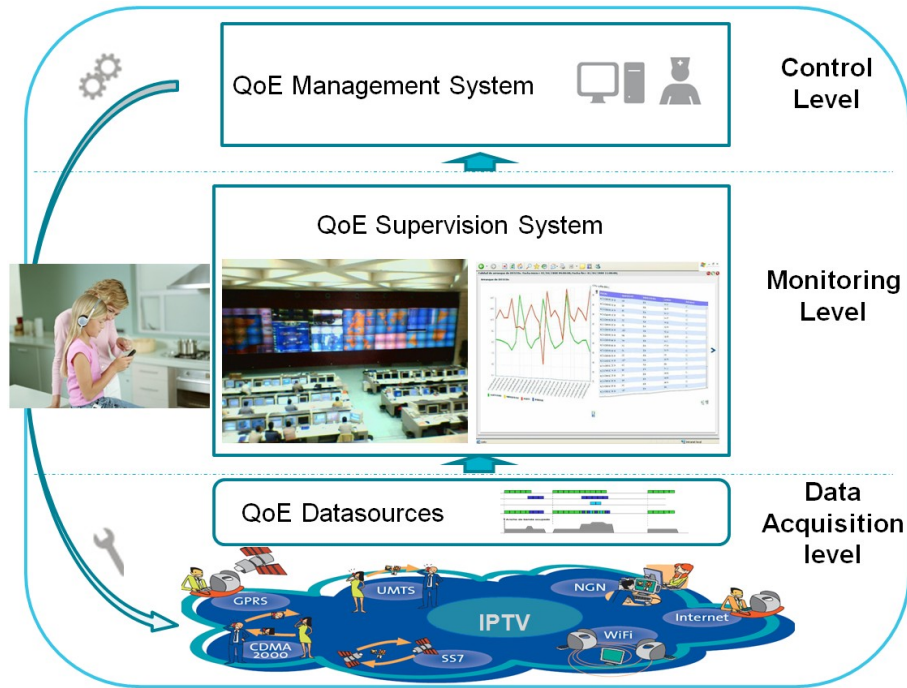
Figure 1. Overview of the Customer Experience Management System which is the scope of the IPNQSIS project

2. TRAFFIC ANALYSIS FOR CONTENT DISTRIBUTION

A CDN is a means of efficiently distributing large volumes of content to users by, *e.g.*, making cached copies of selected content available close to the end users. The benefits of a CDN include reduced demand for transmission (cached content requires less transmission), higher availability (cached content is available from several destinations) and improved performance (less risk of delay and loss). The extent of these benefits depends, however, on the nature of the content itself; a CDN can be made more efficient if most requests concern a stable and small collection of (small) objects and *vice versa*. The popularity of an object tends to follow a cycle of birth, increasing popularity, peak, decreasing popularity and death, and the characteristics of this process typically depend on the nature of the content. A drama, *e.g.*, may have a slow uptake but live for a long time while a news item, *e.g.*, may have a fast uptake but live for a short time. There are also differences within genres; *e.g.*, some dramas enjoy longer periods of fame than others and some news items gain higher levels of attention than others.

In IPNQSIS we will develop mathematical models of content popularity in CDNs based on measurements in a number of Swedish metropolitan networks using deep packet inspection (DPI) and flow classification provided by PacketLogic. The results will complement the existing literature (*e.g.*, [5]–[13]) in a number of ways. To maintain full privacy of the users, all IP addresses will be anonymized automatically and, in addition, access to the data will be restricted to a few persons within Acreo. It is also important to note that the actual measurements are performed by the network operators and that raw data will not be accessed by anybody in the project but only post processed meta data will be accessible to the researchers. This procedure guarantees that no violation of personal integrity will be made.

In particular, we will refine the notion of "popularity" to include **different time windows** and put special emphasis on time scales relevant to caching. In the present literature several popularity distributions are proposed and different explanations have been put forward. The most common explanation points at the time windows and states that the results may be disturbed in longer windows as the request rates of the observed objects may change systematically over time. Other explanations relate to human behaviour, and suggest that some content only is watched once while other content is watched multiple times, or market bottlenecks (*i.e.*, the "perfect market" is impaired by a lack of information), and conclude that some pieces of content would be popular if viewers only knew about them. We will revisit these aspects but take the *view of the users* in our particular networks in addition to the view of a particular portal like YouTube and, furthermore, we will keep track of *different categories/genres*.

Another aspect of particular interest is the **evolution of popularity**. Measurements on YouTube have suggested that videos that become popular remain popular for long periods of time and *vice versa*. Moreover, studying the number of request for a video over time, it has been shown that the life span of a video can range from a few weeks to a few years. There are several explanations for this, one of which is that more popular videos will be promoted through recommendation systems and because of this they become even more popular while less popular videos will not be promoted in this way and because of this they will become less popular. Our studies

will widen the scope to other portals but YouTube and again we will take the *view of the users* in our research. The results will be used to investigate different features of a number of possible caching strategies such as, *e.g.*, the potential of a large number of low cost caches placed very close to the end users or even peer-to-peer technologies in which caching can be said to take place in the user equipment. This points at a novel aspect of our approach; we intend to form different groups of users with respect to, *e.g.*, technical equipment (access rate, browser, operating system *etc*.) and social factors (area of living *etc*.). The purpose of this discrimination is to study the potential of "tailor made" caches, where certain types of content are cached in certain areas while other types of content are cached in other areas. The caching strategy of choice will affect the overall power consumption of the content distribution framework. This will not be dealt with in IPNQSIS. Nonetheless, these issues will be investigated in another project, eWIN, a part of the Swedish National Strategic Research Area "The Next Generation".

3.   OPTIMIZATION OF QUALITY OF EXPERIENCE

The concept of Quality of Experience (QoE) is complementing the ubiquitous Quality of Service (QoS) concept with a more application oriented and user-centric view of how quality is perceived in a communication system or service. Whereas QoS is determined by technological network performance parameters, such as packet loss rate or latency, QoE is the subjective experience perceived by a user of a system or service. Thus, as discussed by Kilkki [14], Reichel [15] and others, QoE concerns the quality delivered from an application to a user, whereas QoS refers to the quality delivered by the network to an application. This distinction is also reflected in how QoS and QoE can be measured. Whereas QoS is measured by network probes or network monitoring tools (e.g. PacketLogic), QoE is measured through subjective quality experiments (e.g. based on ITU-R BT.500-11 [16]).

QoE is defined by the ITU as "The overall acceptability of an application or service, as perceived subjectively by the end-user" [17]. Thus, to directly measure the QoE, the end user has to be involved. However, since there is a strong correlation between the QoS delivered by the network and the QoE experienced by the user, a simplified model of the human experience of an application or service can be designed, so that the QoE can be computed automatically from the QoS, even in real time if needed. This will make it possible to implement more application aware and user-centric quality metrics into network monitoring tools or to optimize the quality delivered by end-systems for different applications. The QoE models can range from simple heuristics (relating for instance the observed packet loss rate to an absolute category rating scale) to complex psychovisual or psychoacoustic models.

In the IPNQSIS project the approach is to develop tools and methods to measure QoS parameters and use these measurements as input to a traffic analysis framework involving QoE models. Traffic monitoring, analysis and modeling are thus coupled to QoE modeling, with the aim of optimizing the performance of applications or services. The applications and services that are in focus are demanding multimedia communication services, including IPTV, VoIP and videoconferencing. The QoE models developed in the IPNQSIS project will be based on traffic measurements and subjective user experiments, mainly targeting different IP video applications. To be useful, the QoE models will need to be application specific, but a significant amount of generality can be expected for QoE models of related applications. For instance, the QoE models used for predicting IPTV performance can be expected to be useful also for videoconferencing, although some aspects such as low latency requirements are very different between those applications.

The IPNQSIS framework consisting of traffic monitoring, analysis and service optimization components can be effective at different time scales depending on the application. At one end we have the content delivery network optimization case, discussed above, wherein the traffic monitoring and analysis are targeting the optimization of caching strategies and network provisioning decisions. On the other end we have the interpersonal voice and video communication services, where the optimization of the QoE must be performed in real time by adapting encoding and transmission parameters based on the measured network performance. In the former case, the optimizations are typically evolving more slowly over time, *e.g.*, by updating the caching strategy based on access statistics, user distribution and streaming performance measurements, whereas in the latter case media codec parameters and error correcting codes are adapted based on QoE estimations in real time. Although the time scales are different, the goals of the optimizations are similar and it is interesting to note that there are many common reusable technological components (*e.g.*, traffic monitoring, probes, traffic analysis mechanisms, QoE models). By exploiting this observation we can gain leverage in research and development activities regarding QoE for multimedia communication services and efficient content distribution networks, both within the IPNQSIS project and on a larger scale.

4.   CONCLUSION

In this paper we have explored the opportunities of leveraging network and traffic measurements for content distribution and interpersonal communication services. We have identified research challenges and outlined how these will be tackled in the newly started IPNQSIS project. Specifically, we have pointed out the importance of studying QoE in addition to QoS when analyzing traffic measurements with the objective of optimizing the

performance of applications and services. This observation is valid at different time scales, both for optimization of content distribution mechanisms, and for adaptive approaches to improve the quality of interpersonal communication services in real time. In a framework for traffic monitoring and analysis coupled to QoE models, such as the one proposed in the IPNQSIS project, we note that there are great opportunities for reuse of generic technological components, algorithms and underlying mathematical models for different applications in different contexts. This will increase the opportunities of leveraging network and traffic performance measurements to improve the quality of future content distribution networks and interpersonal communication services.

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