TRACKING AND MANAGING QOE IN THE INTERNET: TOWARDS COOPERATIVE QOE MANAGEMENT SCHEMES

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SUMMARY

With many different players involved in the end-to-end service delivery chain, identifying the root causes of QoE impairments and finding effective solutions for meeting the end users' requirements and expectations in terms of service quality has become a challenging task. The majority of QoE-based management approaches to-date may be primarily related to either network management or application management, hence different QoE optimization and control loops are involved and interact (e.g., dynamic application adaptation, network resource management). A research question we aim to address is to what extent cooperative management schemes and underlying business models involving multiple players can achieve efficient management of network/system resources, while enhancing customer QoE. Furthermore, it is necessary to identify solutions for the coordination and information exchange among actors involved in the service delivery chain in order to provide channels for effective QoE control/improvement. This white paper provides an overview of research interests within the NetMedia research group (FER, Univ. of Zagreb) as related to topics in the context of tracking and managing QoE in the Internet.

TOWARDS A RESEARCH AGENDA FOR TRACKING AND MANAGING QOE

Today we are witnessing many different players involved in E2E service delivery, ranging from various cloud providers, content providers, network operators, etc. We are further witnessing a shift towards an Internet of Services, envisioning everything on the Internet as a service, and resulting in complex service delivery chains involving multiple players [1]. Looking to put the end user perspective into focus, research in the domain of QoE has gained increasing momentum over the past years.

In the aim to set a research agenda for tracking and managing QoE in the Internet, there is a need to first understand QoE in terms of user perceived quality metrics and underlying influence factors. While often highly dependent on technical QoS delivered by the underlying communication system, QoE extends the notion of QoS by additionally considering the impact of user and context related factors [9][6]. In addition to understanding what impacts QoE, there is a need to understand and model what constitutes QoE, in terms of different subjective and objective quality metrics. Systems for tracking and estimating QoE rely on QoE models to specify the mapping between KPIs and QoE metrics. Following the detection of QoE impairments and root causes, control and management systems are needed to maintain target levels of end user QoE.

UNDERSTANDING THE END USER PERSPECTIVE: QOE MODEL DEVELOPMENT

The development of effective QoE management solutions inherently calls for a multidisciplinary approach needed to study and understand the factors impacting the end user perceived quality and overall experience of using a given service or application, including system, user, and context factors, as outlined in the scope of a white paper published by the COST Action QUALINET community [25]. Such an approach combines knowledge from engineering/networking, psychology, and system design. While different QoE models and assessment methodologies have been studied and standardized for different types of services (e.g., conversational voice services, streaming audio-visual services, interactive data services), the advances in networking technologies and end user device capabilities, changing user behavior and expectations, and new and emerging services, have opened up a large research field aimed at understanding user quality perception. A layered approach considers the mapping of network and system performance indicators to application layer KPIs, and finally to QoE [4]. At each layer, additional context factors may be taken into account to refine model development [15]. Such a mapping is a necessary prerequisite for identifying the root causes of QoE impairments.

In our current research related to QoE modeling, we are studying the relationships between QoE influencing factors and quantifiable QoE dimensions for interactive applications (example case studies: traditional online and cloud–based gaming, video conferencing, Web applications) aimed at going beyond only technical performance (QoS) to encompass user and contextual factors. Cloud gaming represents one of the most compute and bandwidth intensive applications, involving real-time user interaction with a cloud system through sent user commands, and the streaming of rendered video from the cloud to an end user device. Multi-party video conferencing applications involve human-human interactions, incorporating real-time audiovisual communications. Interactive applications in general impose challenges in the sense that system behavior depends on user interactions, rather than pre-recorded and controlled settings. We have previously run subjective studies in various environments, including controlled laboratory settings [13][16][18], in field and home settings [1][11], and via crowdsourcing [12][19]. Based on the results of empirical studies, we are aiming to propose QoE-driven *application adaptation strategies*, specifying how to optimally adapt an application in light of changing resource availability and user/context factors.

QOE MONITORING AND MANAGEMENT

QoE models dictate the parameters to be monitored and measured, with monitoring solutions deployed at different parts of the network needed to identify the root causes of QoE impairments. An important consideration involving monitoring is specification of monitoring points, determination of what parameters to measure and at what level of granularity, and who such measurements should be exposed to. In the scope of the EU Celtic Plus QuEEN project [29], we worked towards specifying a generic monitoring framework for QoE [7], the results of which were also published as ETSI TS 103 294 "*Speech and multimedia Transmission Quality (STQ); Quality of Experience: A Monitoring Architecture*".

QoE-based management approaches to-date may for the most part be related to either network management (based on monitoring and exerting control on access and core network level) or application management (adaptation of quality and performance on end-user and application host/cloud level) [8][5]. For example, OTT services (e.g., Netflix, YouTube, Skype, etc.) delivered by third party service/content providers commonly implement QoE control schemes on the application level by adapting the application to network conditions measured by client devices. In addition, CDN load balancing, server selection strategies, and content placement strategies are employed to maximize QoE. While monitoring solutions deployed on client devices provide a reliable and accurate view of application layer KPIs [30] (e.g., video bitrate, rebuffering duration, etc.) which can be further mapped to user perceived QoE (based on existing and emerging QoE models), rarely is feedback provided to network operators. One initiative in the direction of publishing wide-scale YouTube client-side monitoring KPIs is the development of YouSlow [28], a system designed to monitor YouTube rebuffering events on clients, collect reported data on Google maps, and calculate ISP statistics in terms of rebuffering duration and location. However, quality adaptation decisions driven solely by clients may have limited potential in optimally (e.g., in terms of QoE, fairness) resolving cases of multiple users sharing a bottleneck link and running applications such as HTTP adaptive streaming.

ISPs, on the other hand, commonly rely on performance and traffic monitoring solutions deployed within their access/core network to obtain insight into impairments perceived by end users, thus attempting to identify root causes of potential problems. A study of the challenges and possibilities in identifying the root causes of QoE impairments in the concrete case of YouTube video delivery is given in [27]. Once again considering the example of YouTube, previously available mechanisms for QoE-related performance evaluation rely on information extraction from the HTTP headers of video flows. However, with the switch to HTTPS and ISPs being "left in the dark", new challenges arise with respect to attempting to derive application layer KPIs from network measurements. In that context, one area of interest is the possibility for detecting application-layer KPIs from traffic measurements in the access/core network. Furthermore, studies are needed to determine to what extent root causes of impairments can be determined from such measurements, and the potential for improving root cause detection accuracy through cooperative information exchanges among the network operator and service provider.

The effectiveness of existing QoE management/control approaches is potentially limited due to a lack of information exchange and cooperation among players involved in service delivery [26]. In cases when the quality adaptation process is controlled solely by service endpoints (client and/or server), the result is that adaptation decisions are made on a per-service basis. Such an approach does not allow for global optimization and management [24], e.g., for optimal allocation of shared wireless network resources among multiple concurrent users. Hence, a certain level of coordination among different autonomous control mechanisms may be needed. Questions arise as to how multiple and independent control loops interact and impact QoE? Involved players need incentives to engage in cooperative efforts (e.g., information exchange, content caching, etc.), e.g., a service/cloud provider looking to maximize customer QoE, and a network provider aiming for efficient use of network resources. As discussed at a recent Dagstuhl seminar focused on addressing the challenges of going from QoE assessment to application, an important consideration are the economical and monetization aspects of QoE [22][23][14]. What solutions are needed for coordination and information exchange among actors involved in the service delivery chain in order to provide channels for effective QoE control/improvement? Finally, an unavoidable question is what are the implications of network neutrality regulation on potential QoE management and control solutions?

We are interested in studying QoE management schemes exploiting QoE models and business models centered around cooperative efforts between cloud/service providers and network operators in order to achieve efficient utilization of network/system resources, while enhancing the end user experience when using multimedia applications (e.g., cloud gaming, multiparty video conferencing, adaptive video streaming). For example, offering application providers access to network-related performance information through APIs could provide the potential for enhanced network-aware adaptation decisions. Similarly, offering network providers access to application-level requirements could provide the potential for application-aware and QoE-driven cross-layer resource management. In that regard, the SDN paradigm is a promising solution in this direction. In previous and ongoing work we have been considering the applicability of using negotiated multimedia adaptation paths for the purpose of QoE-driven path assignment in the network based on an SDN approach [17][20]. We have further studied and compared user-centric and network-centric approaches to QoE-driven utility-based optimization of network resource allocation [10], and are further studying resource allocation and service adaptation algorithms [3][21] targeting different optimization strategies and taking into account multiple stakeholder perspectives.

ACKNOWLEDGEMENTS

Research activities are supported in part by the Croatian Science Foundation under the project UIP-2014-09-5605 "*Cooperative Quality of Experience Management for Interactive Cloud-Based Multimedia Applications in Mobile Networks*". Research has also received funding from the project "*Information and communication technology for generic and energy-efficient communication solutions with application in e-/m-health (ICTGEN))*" co-financed by the EU from the European Regional Development Fund, and from EU COST Action IC1304 ACROSS, "*Autonomous Control for a Reliable Internet of Services*".

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