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Vlado Menkovski

Computational Inference and Control of Quality in Multimedia Services

Doctoral Thesis accepted by
Eindhoven University of Technology, The Netherlands

Springer

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To my parents, Angel who dedicated his life to his sons and Snezhana whose strength inspires me deeply.

Supervisor's Foreword

Streaming video over packet-based communication networks is as important as it is difficult. At their conception in the 1960s, the Internet protocols that we still use today were not designed for this use but were meant for asynchronous communications (such as emails) rather than time-constrained media (such as audio and video). On the other hand, videos were originally analog signals, only meant for local replay in movie theaters. Yet today the predominant Internet traffic is made of video streams in all sorts of forms, video-on-demand, IPTV, conferencing, peer-to-peer, and so forth. This requires videos to be digitized, compressed, split in packets, transmitted over lossy networks, and then reconstructed on a player. At each stage, important information is lost, which makes it difficult to push video over networks that can lose large chunks of data by way interference, congestion, latency, and whatnot.

How much bandwidth is necessary to ensure a transmission of 'good' quality? How far can we shrink a stream? How can we broadcast to a large audience in real time? It turns out that these broad questions are largely unanswered and scientists are still busy sorting out the pieces of this complex puzzle. How can we actually measure video quality, which involves forays in the mysterious realm of human perception? How do the individual stages of video transmission affect 'perceived' quality? In which ways should we re-design the network to be more video-friendly?

Despite this large knowledge gap, video services are proliferating and thanks to an engineering trick that goes under the name of 'overprovisioning.' Until we know how to best master the transmission of time-critical media over packet-switching networks, the only option we have is equip the network with an excess of capacity and servers. This practice is utterly expensive and energy-demanding and unsustainable in the longer term, considering the relentless request for video services.

As new technologies stack on top of each other, the interactions among the various pieces become evidently intricate and obscure. Some people think that attempting to master the complexity of Internet systems is a lost cause, thus advocating the 'overprovisioning' route as the only viable avenue. My line of thought goes the other way and I believe that, as scientists, we need to find ways to

reduce the energy footprint of the Internet. In turn, we need to understand the mutual influence between networks and services, and study new ways to control them optimally.

The work that Vlado Menkovski describes in this book makes a number of breakthroughs at the intersection between networks, video services, human perception, and computational intelligence. He shows various ways in which machine learning may be used to assess the quality of current media streaming methods and to make them more efficient. While reading the book, at some point you will realize why 'quality of experience management' is not merely a control problem—it is a matter of prediction. I truly hope that you will enjoy reading this book as much as I have enjoyed working with Vlado, and that you will find it not only useful but also full of inspirational ideas.

Eindhoven, The Netherlands
October 2015

Prof. Antonio Liotta
Chair of Communication Network Protocols

Preface

Quality is the degree of excellence we expect of a service or a product. It is also one of the key factors that determine its value. For multimedia services, understanding the experienced quality means understanding how the delivered fidelity, precision, and reliability correspond to the users' expectations. Yet the quality of multimedia services is inextricably linked to the underlying technology. It is developments in video recording, compression, and transport, as well as display technologies that enable high quality multimedia services to become ubiquitous. The constant evolution of these technologies delivers a steady increase in performance, but also a growing level of complexity. As new technologies stack on top of each other the interactions between them and their components become more intricate and obscure. In this environment optimizing, the delivered quality of multimedia services becomes increasingly challenging. The factors that affect the experienced quality, or Quality of Experience (QoE), tend to have complex nonlinear relationships. The subjectively perceived QoE is hard to measure directly and continuously evolves with the user's expectations. Faced with the difficulty of designing an expert system for QoE management that relies on painstaking measurements and intricate heuristics, we turn to an approach based on learning or inference. The set of solutions presented in this work rely on computational intelligence techniques that do inference over the large set of signals coming from the system to deliver QoE models based on user feedback. We furthermore present solutions for inference of optimized control in systems with no guarantees for resource availability. This approach offers the opportunity to be more accurate in assessing the perceived quality, to incorporate more factors, and to adapt as technology and user expectations evolve. In a similar fashion, the inferred control strategies can uncover more intricate patterns coming from the sensors and therefore implement farther-reaching decisions. Similarly to biological systems, this continuous adaptation and learning make these systems more robust to perturbations in the environment, longer lasting accuracy, and higher efficiency in dealing with increased complexity. Overcoming this increasing complexity and diversity is crucial for addressing the challenges of future multimedia system. Through

experiments and simulations, this work demonstrates that adopting an approach of learning can improve the subjective and objective QoE estimation, enable the implementation of efficient and scalable QoE management as well as efficient control mechanisms.

Contents