

# Improving Quality of Experience for Network Services



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In pursuit of new revenue opportunities and improving market competitiveness, network service providers are offering new value-added services, such as voice over IP (VoIP), video on demand (VoD), IPTV, and so on. With the increased competition, improving the quality of the offered services as perceived by the users, commonly referred to as the *quality of experience* (QoE), becomes very important as well as a significant challenge to the service providers with a goal to minimize the customer churn yet maintaining their competitive edge. The International Telecommunication Union (ITU) defines QoE as the overall acceptability of an application or service, as perceived subjectively by the end users. It is a measurement of how well a service offering satisfies the end user's expectations about the service and includes the complete end-to-end system effects (client, terminal, network, services infrastructure, etc.). QoE is also a consequence of a user's internal state (e.g., predispositions, expectations, needs, motivation, mood), the characteristics of the designed system (e.g., complexity, purpose, usability, functionality, relevance) and the context (or environment) within which the service is experienced (e.g., organizational/social setting, meaningfulness of the activity, voluntariness of use). Developing tools and techniques for accurately measuring, modeling, and improving QoE in complex end-to-end networking infrastructures has become the focus of many industry R&D initiatives. Several QoE aspects are also addressed by all important standardization bodies and industry fora. At the same time, despite the considerable foundational progress already made, engineering QoE remains a continuing challenge and topic of ongoing research, thus attracting significant interest from academia and industry.

This timely special issue brings together cutting edge research work that addresses the challenging and important area of improving QoE for existing and future network services. Within this context, topics of importance include end-to-end QoE assessment and performance improvement strategies for network services (e.g., IPTV, VoIP, VoD, Internet), modeling of user satisfaction and tolerance to quality degradation, testbed studies of QoE for net-

worked applications, the impact of user mobility on QoE, the impact of radio and network resource utilization and management on QoE, the impact of billing and pricing on QoE, the impact of regulatory issues on QoE, and so on.

In response to the call for papers, 42 submissions were received. The submissions underwent a rigorous review process, following which six outstanding articles were selected for publication in this special issue. Four articles are in the broad area of QoE measurement and assessment, while two articles highlight the QoE aspects of specific services (IPTV and VoIP). We expect the articles to stimulate new ideas in the research community, in addition to providing readers with relevant information and techniques on the main QoE issues of network services.

The first article is by Peter Brooks and Bjørn Hestnes, and is titled "Being Objective and Quantitative about User Measures of Quality of Experience." It focuses on developing the concept of QoE, emphasizing the requirements of its measurement and communication that is suitable for use in the industry. The authors present an explanation of a structured approach to defining and measuring QoE in relation to the quality of service (QoS). The developed QoE measurement includes objective parameters of user performance, thus providing higher validity. The authors argue that global QoE measurements should be possible that would allow industry professionals to compare various services, products, and QoS levels. A structured approach shows QoE to have four essential attributes: the communication situation, service prescription, technical parameters, and user experience.

The article titled "On the Use of RTP for Monitoring and Fault Isolation in IPTV" by Ali C. Begen, Colin Perkins, and Jörg Ott focuses on improving the user perception of a particular group of applications such as IPTV. The use of a network-wide monitoring system that would report on impairments is emphasized as an aid to providers to keep their customers satisfied. The authors describe how the monitoring and reporting features offered by Real-Time Transport Protocol (RTP) with RTP Control Protocol (RTCP) feedback can be used in the network to enhance the IPTV subscriber QoE.

In the article “Application of HoQ Framework to Improving QoE of Broadband Internet Services,” Dohoon Kim presents an integrated model of the House of Quality (HoQ) and analytic hierarchy process (AHP) for quality of network services improvement. The use of HoQ is presented as a tool to measure a user’s QoE related to network performance. The proposed HoQ framework consists of four basic parts: service attributes (SAs), SA relative importance, engineering characteristics (ECs), and relationship matrix. As a part of this framework, a case study for improving QoE of broadband Internet access services is also discussed.

Kuan-Ta Chen, Chi-Jui Chang, Chen-Chi Wu, Yu-Chun Chang, and Chin-Laung Lei, in the article “Quadrant of Euphoria: A Crowdsourcing Platform for QoE Assessment,” present what is called the Quadrant of Euphoria, a user-friendly Web-based platform facilitating QoE assessments in network and multimedia studies. This platform is said to be low cost and represents participant diversity, which provides meaningful and interpretable QoE scores. Subject consistency assurance and a burdenless experiment process are other features of the platform. Following the design of the platform and experimentation process, two network-related case studies (Effect of Packet Loss on VoIP Quality and Comparison of IPTV Loss Concealment Schemes) and crowdsourcing evaluations are presented.

The article “A Generic Quantitative Relationship between Quality of Experience and Quality of Service” by Markus Fiedler, Tobias Hossfeld, and Phuoc Tran-Gia proposes a generic formula in which QoE and QoS parameters are connected through an exponential relationship, called the IQX hypothesis. The formula relates changes of QoE with respect to QoS to the current level of QoE. This article quantifies QoS into an exponential formula which is validated using three case studies that address different QoE parameters: voice quality, user reactions to download times, and throughput limitations. The proposed exponential relationship between QoE and QoS provides better estimates than the original logarithmic approximations.

Finally, the article “Can Skype Be More Satisfying? A QoE-Centric Study of the FEC Mechanism in the Internet-Scale VoIP System” by Te-Yuan Huang, Po-Jung Wang, Kuan-Ta Chen, and Polly Huang examines the forward error correction (FEC) mechanism of one of the most popular VoIP applications, Skype. The article presents a QoE analysis of the FEC mechanism where the optimal redundancy ratio under different network and codec settings are explored by means of emulation. The redundancy ratio with the desired mean opinion score is considered as the optimal redundancy ratio. The authors conclude that Skype can be more satisfactory to users by using a more sophisticated redundancy control algorithm.

In closing, we would like to thank all those who have made this Special Issue possible: the colleagues who spread the word around advertising the Call for Papers and attracting attention, the many authors who submitted papers to our special issue, the team of reviewers whose thorough reviews helped us in selecting and further improving the outstanding articles that appear in our Special Issue, the Editor-in-Chief Tom Chen (as well as members of the editorial board) for invaluable help and for

hosting this special issue, and ComSoc’s editorial staff who produced the final material. We hope that all the efforts undertaken meet the readers’ expectations, for whom this Special Issue on Improving Quality of Experience for Network Services has been prepared.

### Biographies

JAHAN A. HASSAN [M] (jahan@cse.unw.edu.au) is a senior research associate at the School of Computer Science and Engineering, University of New South Wales, Sydney, Australia. Prior to joining the University of New South Wales, she worked as a research fellow at the School of Information Technologies, University of Sydney, Australia. She received her Ph.D. in 2004 from the University of New South Wales, and her Bachelor’s degree in 1995 from Monash University, Melbourne, Australia, both in computer science. Her Ph.D. thesis, which proposes innovative solutions for low-cost wireless and mobile networking, was later published as a book by the European publisher VDM Verlag, Germany, in 2008. She has published widely in peer-reviewed conferences and journals, and is the primary author of two provisional patents. She was a member of the Technical Program Committees of IEEE LCN ’06, IADIS AC ’06, IEEE ICC ’07, IEEE ISWPC ’07, IADIS WAC ’07, IADIS WAC ’08, IWQOS ’08, IEEE WCNC ’10, and IEEE GLOBECOM ’10. She has served as a reviewer for many conferences and journals. Her research interests include mobile and wireless networking architectures, wireless resource management, user-satisfaction-based network provisioning, and wireless network security. Her current project focuses on the measurement and modeling of individual users’ wireless network degradation tolerance level.

SAJAL K. DAS [SM] (das@cse.uta.edu) is a Distinguished Scholar Professor of Computer Science and Engineering and founding director of the Center for Research in Wireless Mobility and Networking (CRWMaN) at the University of Texas at Arlington (UTA). He is currently a program director in the Division of Networks and Computer Systems of the U.S. National Science Foundation. His research interests include wireless and sensor networks, smart environments, mobile and pervasive computing, security, applied graph theory, and game theory. He has published over 400 technical papers in these areas and holds six U.S. patents. He coauthored the books *Smart Environments: Technology, Protocols, and Applications* (Wiley, 2005) and *Mobile Agents in Distributed Computing and Networking* (Wiley, 2010). He is a recipient of several Best Paper Awards in conferences such as QShine’09, EWSN’08, IEEE PerCom’06, and ACM MobiCom’99. He is a recipient of numerous awards including the IEEE Technical Achievement Award (2009), Lockheed Martin Award for Teaching Excellence (2009), IEEE Region 5 Outstanding Engineering Educator Award (2008), UTA Academy of Distinguished Scholars Award (2006), and University Award for Distinguished Record of Research (2005). He serves as the Founding Editor-in-Chief of *Pervasive and Mobile Computing*, and Associate Editor of *IEEE Transactions on Mobile Computing, ACM/Springer Wireless Networks, IEEE Transactions on Parallel and Distributed Systems*, and *Journal of Peer-to-Peer Networking*. He has served as General or Technical Program Chair and TPC member of numerous IEEE and ACM conferences.

MAHBUB HASSAN [SM’00] (mahbub@cse.unsw.edu.au) is a full professor in the School of Computer Science and Engineering, University of New South Wales. He received a Ph.D. in computer science from Monash University (1997), an M.Sc. in computer science from the University of Victoria, Canada (1991), and a BSc. in computer engineering from Middle East Technical University, Turkey (1989). He was an invited professor at the University of Nantes, France, April–May, 2005, and a principal researcher at the National ICT Australia in 2004–2005. He serves as Editor-in-Chief of *ICST Transactions on Networks and Communications* and Area Editor for *Computer Communications*. In 1999–2001 he was an Associate Technical Editor for *IEEE Communications Magazine*. He has served as Guest Editor for *IEEE Communications Magazine*, *Journal of Supercomputing*, and *Real Time Imaging*. He was chair of IEEE ICON Wireless Workshop, Sydney, 2003, and foundational co-chair for the SPIE conference on Internet Quality of Service in 2001–2003. He is the lead author of the book *High Performance TCP/IP Networking: Concepts, Issues and Solutions* (Prentice Hall, 2004), and a co-author of *Engineering Internet QoS* (Artech House 2002). His research interests include quality of service for communication networks, vehicular communications, mobile computing, wireless ad hoc and sensor networks, and high-speed packet switching networks. He has published over 100 technical papers in these areas and holds one U.S. patent. He was the keynote speaker for the IEEE International Workshop on Vehicular Networking 2009. He is a member of the ACM.

CHATSCHIK BISDIKIAN [F’04] (bisdik@us.ibm.com) holds a Ph.D. degree in electrical engineering from the University of Connecticut, Storrs. He is a research staff member with the Network Management Department at IBM T. J. Watson Research Center, Hawthorne, New York. He has been with IBM Research since 1989 and has worked in numerous projects covering a variety of research topics in communications, networking, pervasive computing, IPTV services, computer system management, sensor networks, and so on. In 2004 he was elected IEEE Fellow for his contributions to the development, modeling, and analysis of communication protocols and wireless personal area networks. He has authored over 100 peer-reviewed papers and several patents issued in the aforementioned areas, and

co-authored the book *Bluetooth Revealed* (Prentice Hall). He has served as the Editor-in-Chief of *IEEE Network*, which he currently serves as Senior Technical Editor. He also serves on the editorial board of *Pervasive and Mobile Computing* and has served on the editorial boards of *IEEE Journal on Selected Areas in Communications* and *Telecommunication Systems*; he has also guest edited several special issues on various topics. He served as the Technical Program Chair for IEEE PerCom'09, and served as chair of the First IEEE Workshop on Quality of Information (QoI) for Sensor Networks (QoISN '08) and the Workshop on End-to-End, Sense-and-Respond Systems, Applications, and Services (EESR '05). He has been involved with the development of the Bluetooth specification from its early stages and has served as vice-chair of the IEEE 802.15.1 task group that developed a standard for personal area networks adapted from the Bluetooth specification. He received the 2002 best tutorial award from the IEEE Communications Society for his paper titled "An Overview of the Bluetooth Wireless Technology." He is a 1995 finalist of the Eta Kappa Nu Honor Society's Outstanding Young Electrical Engineer Award Program and a 2004 inductee of the Academy of Distinguished Engineers and Hall of Fame of the School of Engineering of the University of Connecticut. He is a lifelong member of the Eta Kappa Nu and Phi Kappa Phi Honor Societies, and a member of ACM.

DAVID SOLDANI (david.soldani@huawei.com) received an M.Sc. degree with maximum score and *cum laude approbatur* in electronic engineering from the University of Florence, Italy, in December 1994; and a D.Sc. degree in technology with distinction in networking technology from Aalto University, Finland, in October 2006. From 1997 to 2007 he was at Nokia in various technical and

research management positions. From 2007 to 2009 he was a research director and head of Customer Networks & Solutions and Solutions & Services Innovation functions, Research Technology & Platforms (RTP), Nokia Siemens Networks (NSN), Munich, Germany. In this role, he was responsible for driving the alignment between the RTP research portfolio, the NSN network architecture vision and technology strategy, and future customer needs, and driving innovative research projects for improving professional services and solutions. Prior to joining Nokia, he was a graduated officer at the Italian Military Navy, Livorno, Italy. He is currently head of the IP Transformation Research Centre (IPTRC), Huawei European Research Centre, Munich, Germany. In his current role he is responsible for driving the alignment between Huawei all-IP E2E solutions and future customer needs, taking a holistic view of both service requirements and how these requirements affect the structure, technology, and network components of the optimal solution for each part of an operator's network. His areas of technical competence include wireless mobile systems (TETRA, GSM, EDGE, WCDMA, HSPA, LTE/SAE, and WiMAX), QoE and QoS, network planning and optimization, transport network layer technologies (IP/MPLS/Ethernet), and wireline broadband access technologies (xDSL, xPON). He has been selected five times to receive special rewards in recognition of his role, commitment, professionalism, and contribution at Nokia and Nokia Siemens Networks. He has published or presented over 20 international papers, contributed to the publication of four books, and holds five international patents. He has taken part in several IEEE Technical Program Committees for international conferences, journals, magazines, and workshops in areas of wireless mobile systems.