



University of Zagreb

Faculty of Electrical  
Engineering and Computing

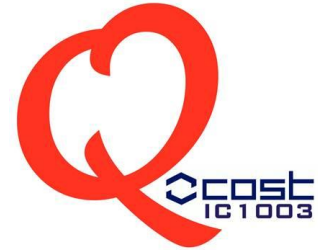
# Tracking and Managing QoE in the Internet: Towards Cooperative QoE Management Schemes

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- ◆ Past and ongoing research efforts in the more general domain of QoE
- ◆ QoE modeling
- ◆ QoE monitoring and management: cross-layer and cooperative management
- ◆ Challenges and open questions

- ◆ COST action QUALINET: “European Network on Quality of Experience in Multimedia Systems and Services”
- ◆ Duration: 11/2010 – 11/2014
- ◆ Members: 27 European countries and 6 non- European countries, approx. 200 researchers involved
- ◆ Still ongoing but currently without formal COST support



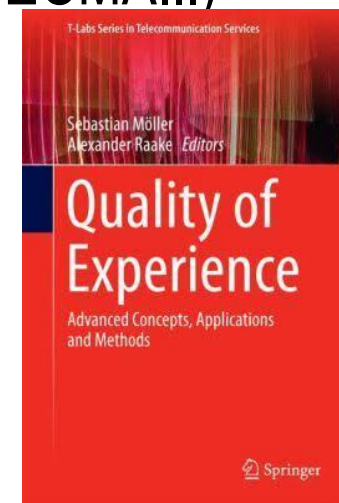
**Main objective:** methodologies for subjective and objective quality metrics → focus on current and new trends in multimedia communication systems

# Some key QUALINET outcomes...



Department of Telecommunications

- ◆ *Qualinet White Paper on Definitions of Quality of Experience*  
([http://www.qualinet.eu/images/stories/QoE\\_whitepaper\\_v1.2.pdf](http://www.qualinet.eu/images/stories/QoE_whitepaper_v1.2.pdf))
- ◆ Springer book “*Quality of Experience: Advanced Concepts, Applications and Methods*”
- ◆ Qualinet databases, accessible from the Action website or directly from:  
<http://dbq.multimediatech.cz> : include more than 200 registered databases, widely disseminated
- ◆ Strong collaboration with standardization (ITU, ISO/IEC, ECMA...)
- ◆ Flagship conference: *International Conference on Quality of Multimedia Experience (QoMEX)*
  - ◆ next CFPs deadline March 2016 (to be held in June 2016, Lisbon, Portugal)
  - ◆ <http://qomex2016.lx.it.pt/>

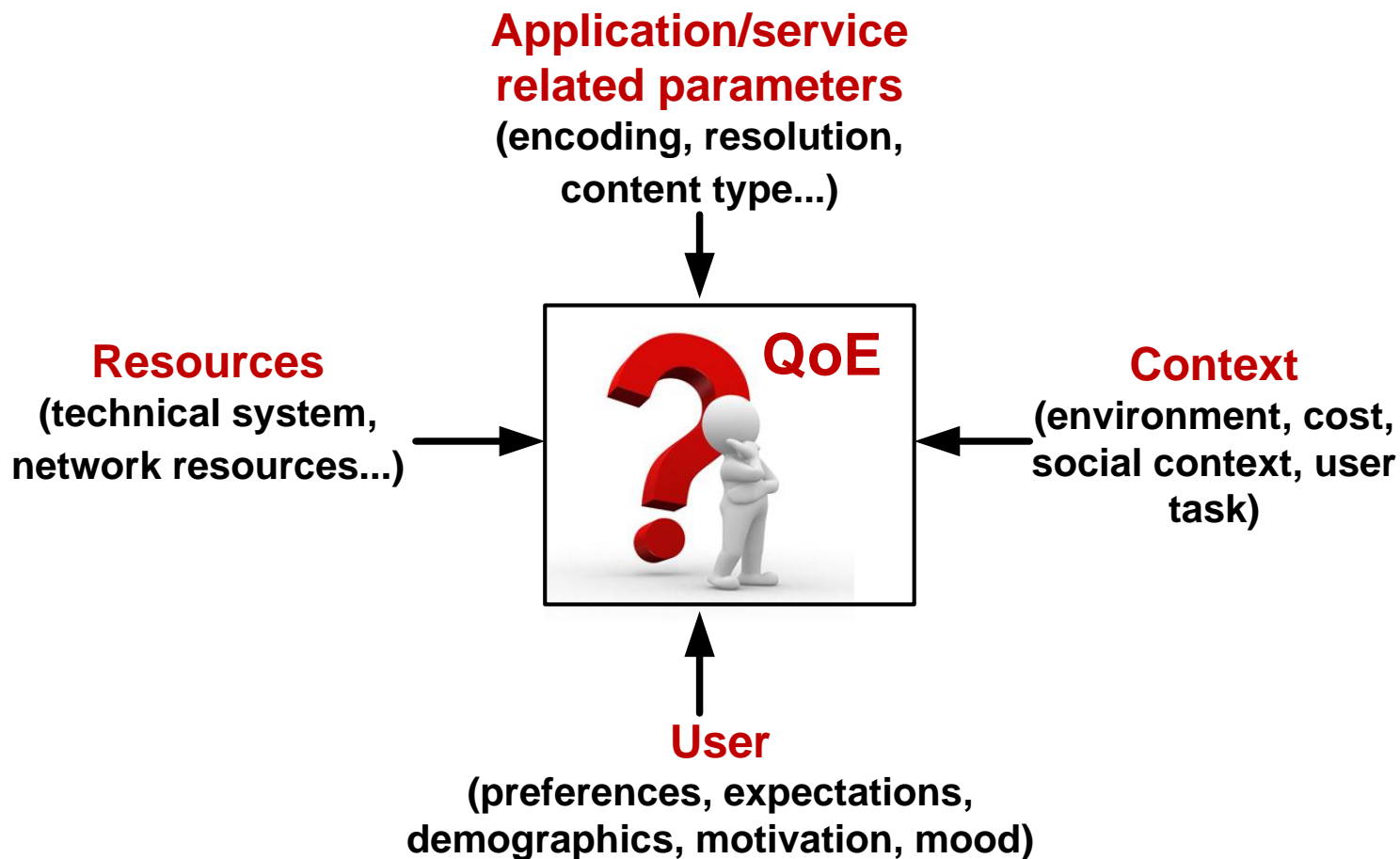


- ◆ 2009: seminar 09192 “*From Quality of Service to Quality of Experience*” (<http://www.dagstuhl.de/en/program/calendar/semhp/?semnr=09192>)
- ◆ 2012: seminar 12181 “*QoE: From User Perception to Instrumental Metrics*” (<https://www.dagstuhl.de/en/program/calendar/semhp/?semnr=12181>)
- ◆ 2015: seminar 15022 “*Quality of Experience: from Assessment to Application*” (<http://www.dagstuhl.de/en/program/calendar/semhp/?semnr=15022>)

*QoE modeling: understanding the end user  
perspective*

# What impacts QoE?

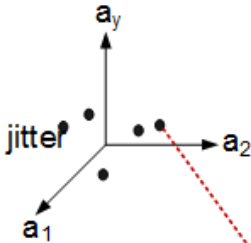
- ◆ long list of influence factors, some difficult (nearly impossible) to measure – go beyond traditional QoS factors



# The ARCU model

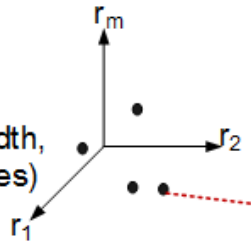
## Application space: $A$

Application configuration related factors (e.g., encoding, resolution, frame rate, content type, jitter, buffer size, error correction functionality)



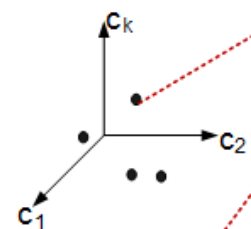
## Resource space: $R$

Network/system factors related to resource characteristics and performance (e.g., bandwidth, loss, delay, server processing, client capabilities)



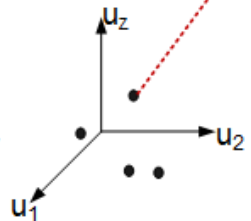
## Context space: $C$

Factors indicating the situation in which a service or application is being used (e.g., ambient conditions, location, time, social conditions, costs, task)



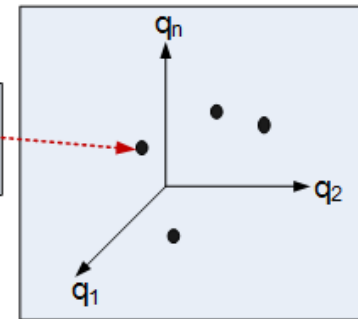
## User space: $U$

Parameters related to the specific user of a given service or application (e.g., user profile, preferences, requirements, expectations, prior experience, motivation)



## QoE Space: $Q$

Dimensions representing quantitative and qualitative quality metrics (e.g., MOS, ease-of-use, efficiency, satisfaction, availability, comfort, utility)



Mapping function

Estimation of Integral QoE (weighted combination of individual QoE dimensions)

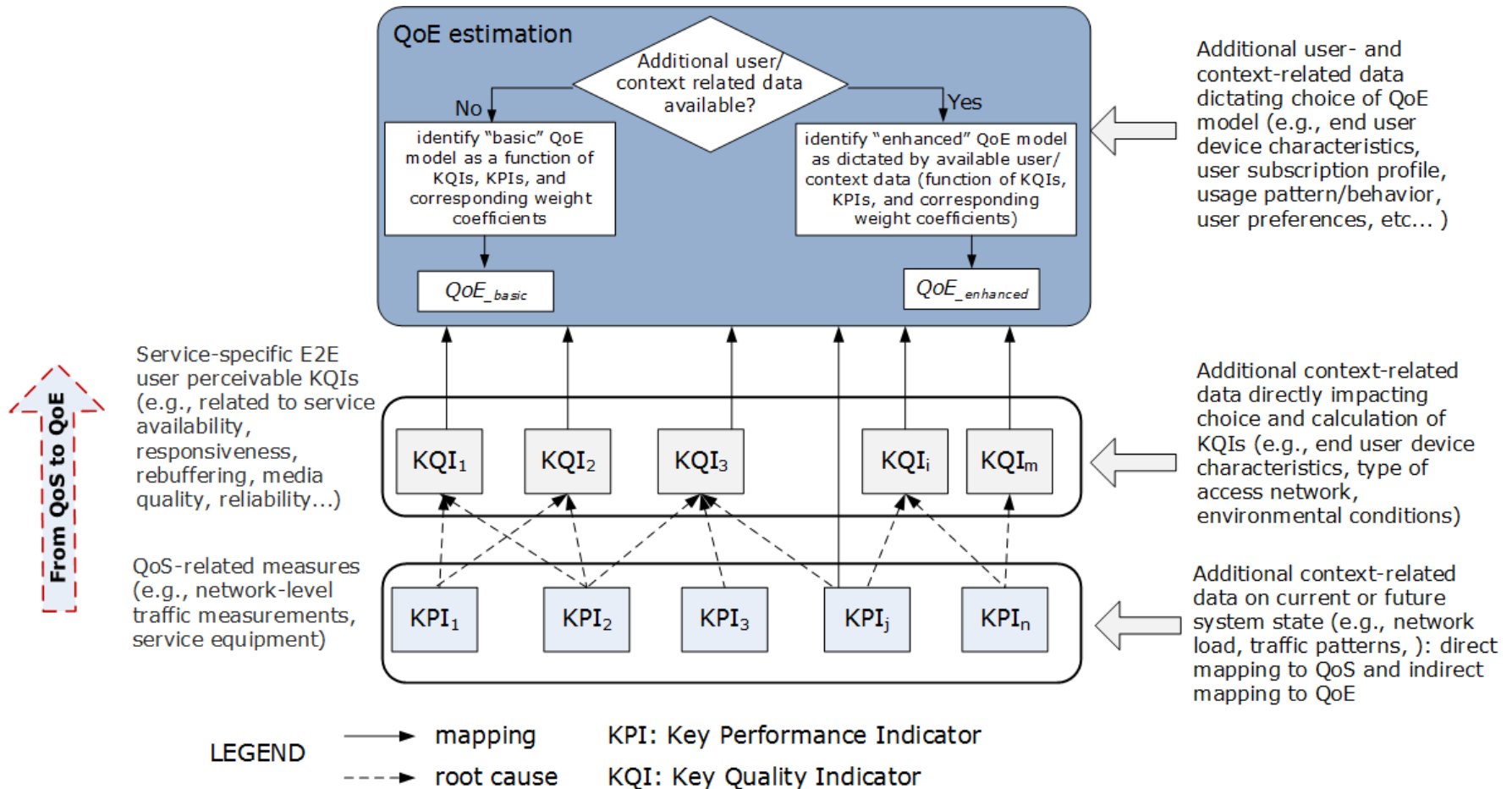
Source: L. Skorin-Kapov, M. Varela. "A Multi-Dimensional View of QoE: the ARCU Model", Proc. of 35th MIPRO, Croatia, May 2012.  
- included also in ETSI TS 103 294 "Quality of Experience, a Monitoring Architecture"



- ◆ Studying relationships between QoE IFs and quantifiable QoE dimensions
  - our focus has been on interactive applications (e.g., cloud gaming, multiparty video conferencing, Web browsing)
- ◆ **QoE-driven application adaptation strategies**: specify how to optimally adapt an application in light of changing network/system resource availability and user/context factors

# *QoE monitoring*

# Mapping between network performance metrics/ traffic features, application-layer KPIs, and QoE

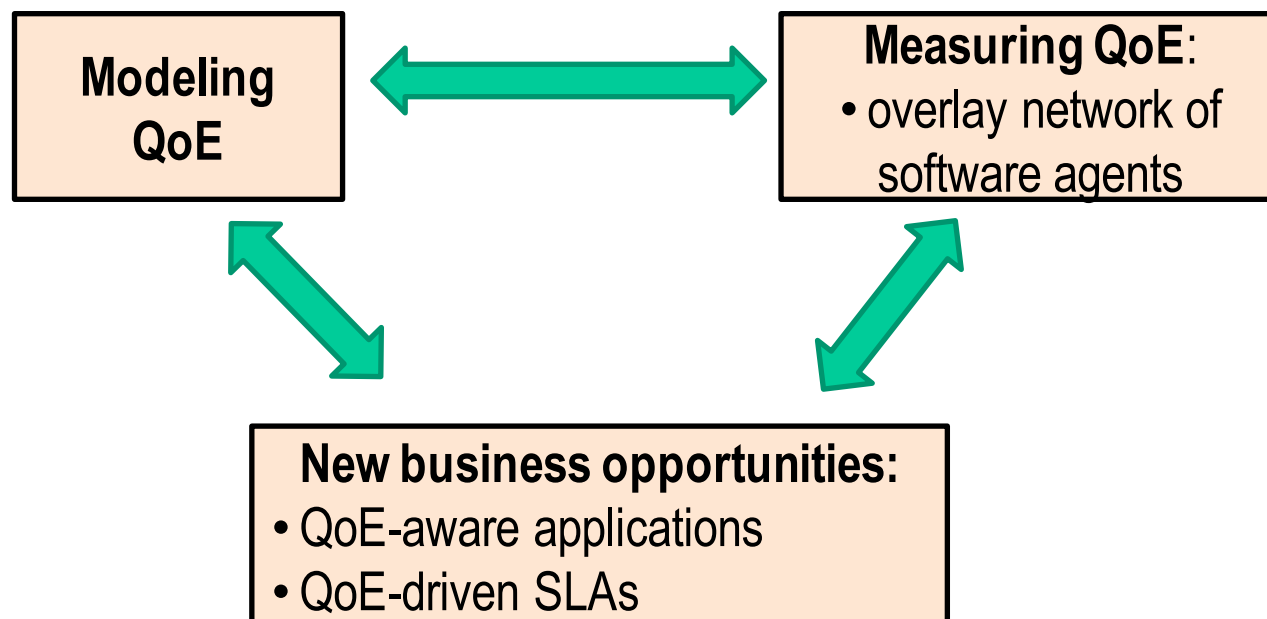


Sources:

- M. Varela, L. Skorin-Kapov and T. Ebrahimi. "Quality of Service vs. Quality of Experience", in "Quality of Experience: Advanced Concepts, Applications and Methods", T-Labs Series in Telecommunication Services, S. Möller and A. Raake (eds.), Springer, March 2014, pp. 85-96
- T. Hoßfeld, et al. "Context monitoring for improved system performance and QoE", under review, extended version of paper "Can Context Monitoring Improve QoE? A Case Study of Video Flash Crowds in the Internet of Services", 3rd IFIP/IEEE International Workshop on Quality of Experience Centric Management (QCMan), Ottawa, Canada, May 2015.

- ◆ ***Quality of Experience Estimators in Networks***
- ◆ Coordinator: Orange Labs / France Telecom (2011-2014)
- ◆ Technical coordinator: VTT Technical Research Centre of Finland
- ◆ 19 member institutions across Europe

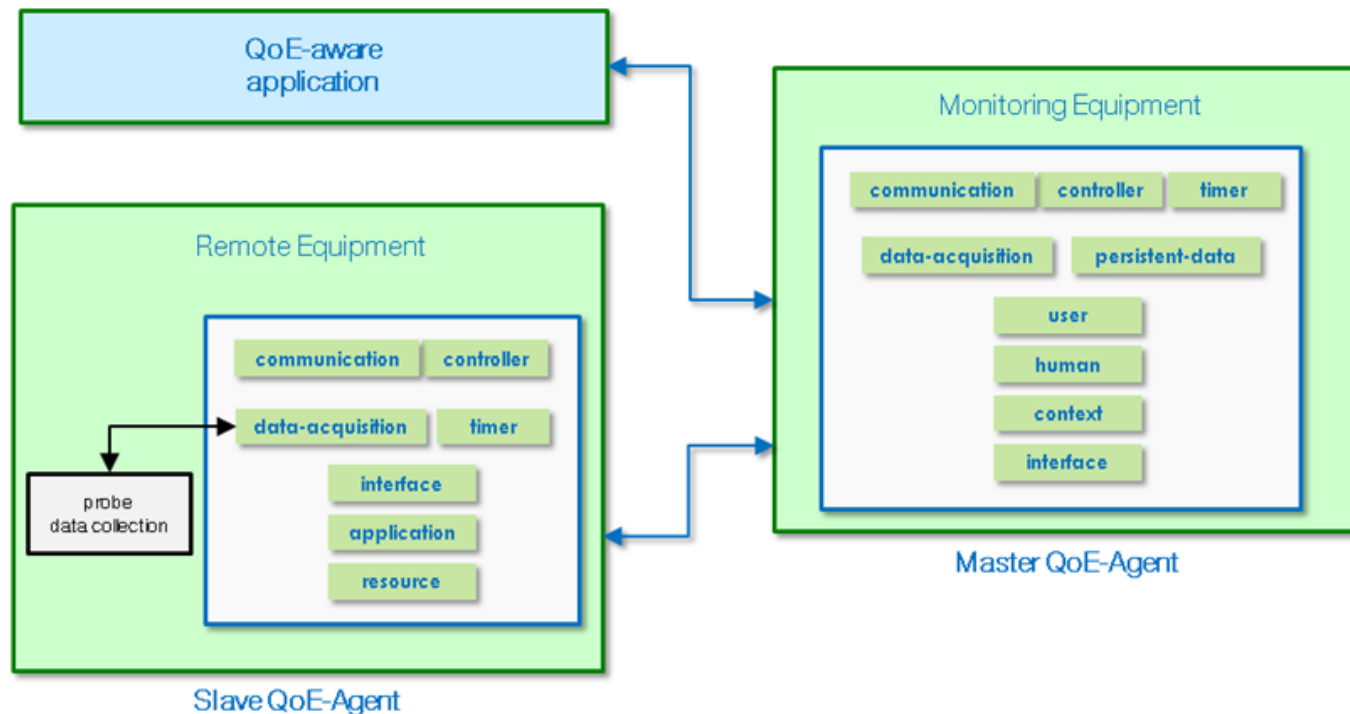
<https://www.celticplus.eu/celtic-plus-project-queen/>



# QuEEN monitoring agents (ETSI TS 103 294 , 2014)



- ◆ See ETSI TS 103 294 (2014-12): **Speech and multimedia Transmission Quality (STQ), Quality of Experience, A Monitoring Architecture**
- ◆ Layered approach to QoE monitoring
- ◆ Implementation of the QoE layered model: the QoE-agent → enable “QoE-aware” applications
- ◆ naming conventions (QoE-specific namespace)

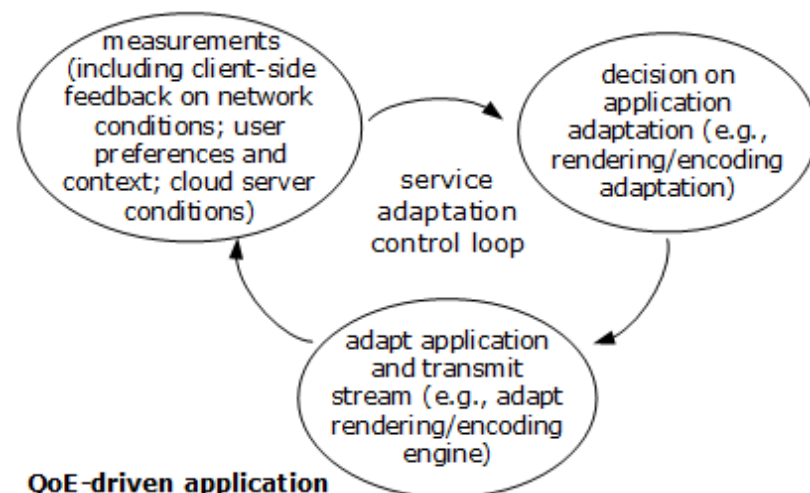


# *QoE-driven network / service management*

- ◆ **Application-layer monitoring (performed at the client or cloud/service provider)**
  - direct application-layer KPI monitoring
  - high accuracy
- ◆ **Network-layer monitoring (performed in ISP network)**
  - Data collected via multiple probes (radio statistics, flow records, etc.)
  - Methodology needed for estimating application-layer KPIs from network data
  - Traffic encryption has left ISPs “in the dark”
  - High complexity of problem (different traffic patterns for different clients, device capabilities, access networks, etc.)
  - QoE impairment root cause analysis, control mechanisms

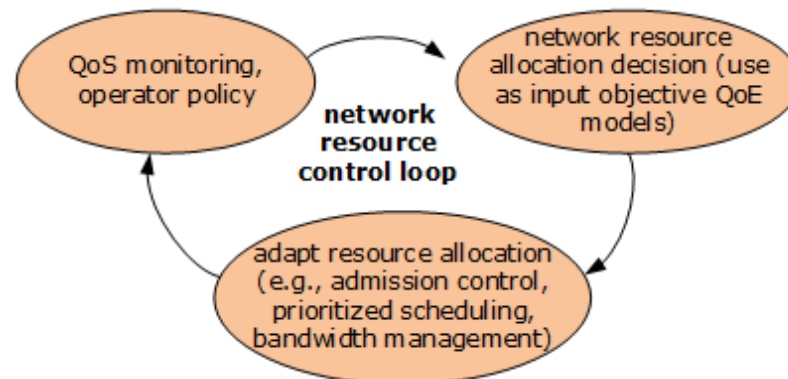
- ◆ **network management**: monitoring and control on core and access network level
- ◆ **application management**: adaptation of quality and performance on end user and application host/cloud level
- ◆ different QoE optimization and control loops involved (e.g. dynamic application adaptation, network management) → *how do they interact?*

## **example control loops**



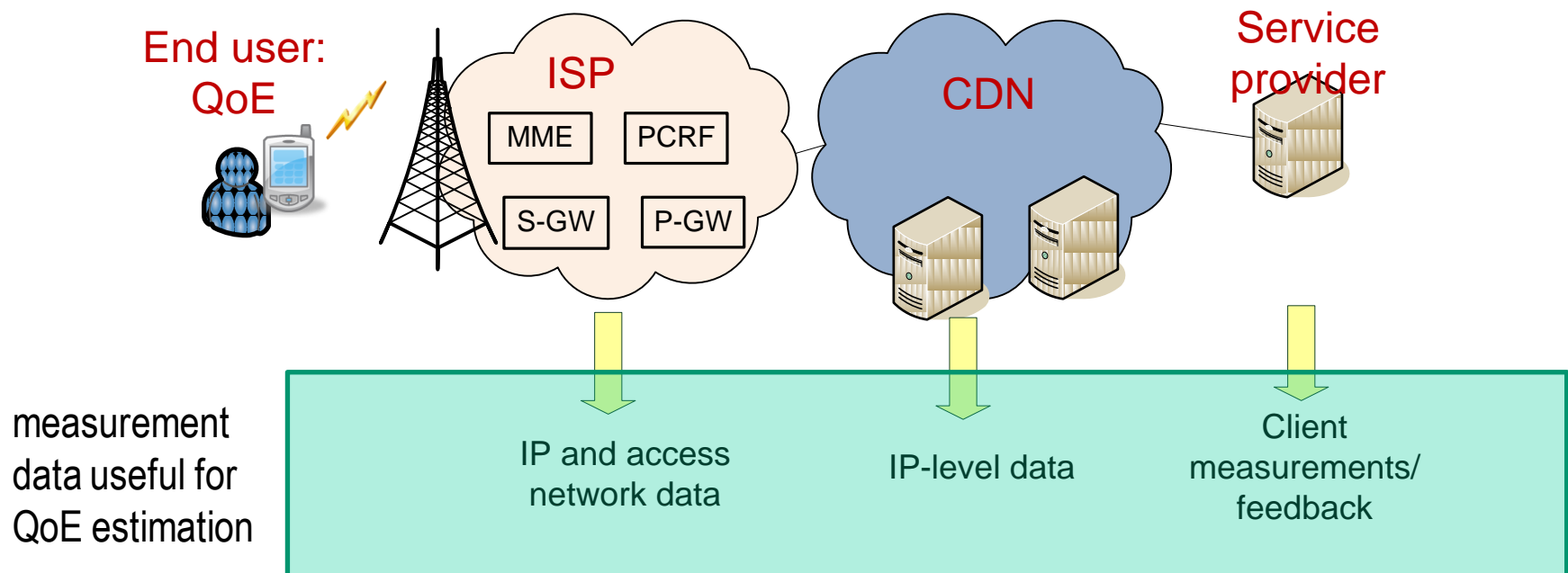
### **QoE-driven application management**

### **QoE-driven network management**





- ◆ many (potentially new) players involved in E2E service delivery
- ◆ paradigm shift towards an *Internet of Services*
- ◆ effectiveness of QoE management/control mechanisms is potentially limited due to lack of information exchange and cooperation among players



- ◆ offering application providers access to network-level performance info through APIs could provide potential for **enhanced network-aware adaptation decisions**
- ◆ offering network providers access to application-level requirements could provide the potential **for application-aware and QoE-driven cross-layer resource management**
- ◆ SDN paradigm is a promising solution in terms of technical realization

- ◆ study how to **utilize empirical knowledge and QoE models** to achieve higher QoE and more efficient management of network/system resources ?
- ◆ **Cooperative QoE management scheme** integrating:
  - service adaptation decisions (e.g., bitrate, resolution, fps adaptation),
  - control at the level of network/system resources, and
  - user feedback mechanisms (e.g., context, user behaviour, preferences, etc.).
- ◆ address underlying business models

- ◆ how can new QoE models be exploited (in a practical sense) in the context of **QoE management schemes**? Many models still missing (e.g., interactive cloud-based applications, gaming)....
- ◆ to what extent can **cooperative business models** involving multiple players (e.g., cloud/service providers, mobile network operators, content providers) achieve more efficient management of network/system resources, while enhancing customer QoE? Stakeholder incentives?
- ◆ what (novel?) solutions are needed for **coordination and information exchange among actors** involved in the service delivery chain in order to provide channels for QoE control/improvement?