QoE Management Framework for Internet Services in SDN Enabled Mobile Networks

Marcus Eckert, Thomas Knoll

QoE Management Framework for Internet Services in SDN enabled mobile networks

Marcus Eckert and Thomas Martin Knoll

Chemnitz University of Technology,
Reichenhainer Str. 70, 09126 Chemnitz, Germany
{marcus.eckert, knoll}@etit.tu-chemnitz.de

Abstract:
In order to achieve acceptable service quality, the broad spectrum of Internet services requires differentiated handling and forwarding of the respective traffic flows in particular within increasingly overloaded mobile networks. The 3GPP procedures allow for such service differentiation by means of dedicated GPRS Tunnelling Protocol (GTP) tunnels, which need to be specifically set up and potentially updated based on the client initiated service traffic demand. The Software Defined Networking (SDN) enabled QoE monitoring and enforcement framework for Internet services presented in this paper is named ISAAR (Internet Service quality Assessment and Automatic Reaction) framework and will be abbreviated as ISAAR herein. It augments existing quality of service functions in mobile as well as software defined networks by flow based network centric quality of experience monitoring and enforcement functions. The following chapters state the current situation followed by the explanation of the ISAAR architecture in chapter 3 and its internal realisation in chapters 4, 5 and 6. In chapter 7 the summary and outlook are given.

Keywords: ISAAR, QoE framework, QoE, quality of experience, QoS, quality of service, measurement, estimation, monitoring, enforcement, DPI classification, traffic manipulation, flow-based QoE enforcement, Software Defined Networking, SDN, OpenFlow.

1 Introduction

Internet based services have become an essential part of private and business life and the user experienced quality of such services is crucial for the users' decision to subscribe and stay with the service or not. However the experienced service quality results from the whole end-to-end line-up from participating entities. It starts from the service generation, covers potentially several transport entities and finishes up in the application displaying or playing the result on the end device's screen or audio unit. However, the contributing performances of the individual service chain parties can often not be separately assessed from the end user perspective. Sluggish service behaviour can thus stem from slow server reaction, transport delay or losses due to congestion along the forwarding path as well as from the end device capabilities and load situation during the information processing and output. More insight can be gained

adfa, p. 1, 2013.

from the mobile network perspective, which potentially allows for a differentiated assessment of the packet flow transport together with a transparent and remote Quality of Experience (QoE) estimation for the resulting service quality on the end device.
User satisfaction and user experienced service quality are strongly correlated and lead - from an Internet service provider point of view - either to an increase in subscription numbers or to customer churn towards competitors. Neither the capabilities and load situations on end devices nor the performance of content provider server farms nor the transport performance on transit links can be influenced by the operator of a mobile network. Therefore, this QoE framework will concentrate on the monitoring and enforcement capabilities of today's mobile networks in terms of differentiated packet flow processing and potentially SDN (Software Defined Networking) enabled forwarding. Since all competing providers will face similar conditions on either end of the service chain, the emphasis on the provider own match between service flow requirements and attributed mobile network resources in a cost efficient manner will be key for the mobile operator business success. That applies especially for SDN enabled networks, where a split between control and data path elements is made. This way, functions traditionally realized in specialised hardware can now be abstracted and virtualized on general purpose servers. Due to this virtualization, network topologies as well as transport and processing capacities can be easily and quickly adopted to the service demand needs under energy and cost constraints. One of the SDN implementation variants is the freely available OpenFlow (OF) standard [1]. With OF the path of packets through the network can be defined by software rules. OF is Ethernet based and implements a split architecture between so called OpenFlow Switches and OpenFlow controllers. A switch with OF control plane is referred to as "OpenFlow Switch". The switch consists of the specialised hardware (Flow Tables), the Secure Channel for communication between switch and OF controller and the OF protocol which provides the interface between them [2].
The Internet Service quality Assessment and Automatic Reaction (ISAAR) quality of experience framework takes this situation into account and leverages the packet forwarding and traffic manipulation capabilities available in modern mobile networks. It focuses on LTE and LTE Advanced networks, but is applicable to the packet domains in 3G and even 2G mobile networks as well. Since different services out of the broad variety of Internet services will ideally require individual packet flow handling for all possible services, the ISAAR framework will focus only on the major service classes for cost and efficiency reasons. The set of tackled services is configurable and should sensibly be limited to only the major contributing sources in the overall traffic volume or the strong revenue generating services of the operator network. The current Sandvine Internet statistic report [3] for instance shows that only HTTP, Facebook and YouTube services alone cover about 65% of the overall network traffic.

2 State of the Art

The standardization of mobile networks inherently addresses the topic of Quality of Service (QoS) and the respective service flow handling. The 3GPP defined architecture is called Policy and Charging Control (PCC) architecture, which started in Release 7 and applies now to the Evolved Packet System (EPS) [4]. The Policy and

Charging Rules Function (PCRF) is being informed about service specific QoS demands by the Application Function (AF). Together with the Traffic Detection Function (TDF) or the optionally available PCRF intrinsic Application Detection and Control (ADC), traffic flow start and end events are detected and indicated to the PCRF. This in turn checks the Subscription Profile Repository (SPR) or the User Data Repository (UDR) for the permission of actions as well as the Bearer Binding and Event Reporting Function (BBERF) for the current state of already established dedicated bearers. As can be seen here, the 3GPP QoS control relies on the setup of QoS by reserving dedicated bearers. These bearers need to be setup, torn down for service flows or modified in their resource reservation, if several flows are being bundled into the same bearer [5]. Nine QoS Class IDs (QCI) have been defined by 3GPP for LTE networks, which are associated with such dedicated bearers. Today, IP Multimedia Subsystem (IMS) based external services and or provider own services make use of this well-defined PCC architecture and setup dedicated service flow specific reservations by means of those bearers. Ordinary Internet services, however, are often carried in just one (default) bearer without any reservations and thus experience considerable quality degradations for streaming and real time services.

Therefore, network operators need to address and differentiate service flows besides the standardized QoS mechanisms of the 3GPP. HTTP based adaptive streaming video applications currently amount the highest traffic share (see [3]). They need to be investigated for their application behaviour and appropriate actions should be incorporated in any QoS enhancing framework architecture. An overview of HTTP based streaming services can be found in [7].

There are many approaches found in the literature, which address specific services and potential enhancements. HTTP Adaptive Streaming Services (HAS) [8] for instance is a new way to adapt the video streaming quality based on the observed transport quality.

Other approaches target the increasing trend of Fixed-Mobile Convergence (FMC) and network sharing concepts, which inherently require the interlinking of PCRF and QoS architecture structures and mechanisms (see e.g. [9]). This architectural opening is particularly interesting for the interlinking of 3GPP and non-3GPP QoS concepts, but has not yet been standardized for close QoS interworking. The proposed interworking of WiMAX and LTE networks [10] and the Session Initiation Protocol (SIP) based Next Generation Network (NGN) QoE Controller concept [11] are just examples of the recent activities in the field.

The ISAAR framework presented in this paper follows a different approach. It aims for service flow differentiation either within single bearers without PCRF support or PCRF based flow treatment triggering dedicated bearer setups using the Rx interface. This way it is possible to use ISAAR as a standalone solution as well as aligned with the 3GPP PCRF support.

The following chapters document the ISAAR framework structure and work principle in detail.

3 QoE Framework Architecture

The logical architecture of the ISAAR framework is shown in Figure 1. The framework architecture is 3GPP independent but closely interworks with the 3GPP PCC. If available, it also can make use of flow steering in SDN networks using OpenFlow. This independent structure generally allows for its application in non-3GPP mobile networks as well as in fixed line networks. ISAAR provides modular service specific quality assessment functionality for selected classes of services combined with a QoE rule and enforcement function. The assessment as well as the enforcement is done for service flows on packet and frame level. It incorporates PCC mechanisms as well as packet and frame prioritisation in the IP, Ethernet, and the MPLS layer. MPLS as well as OpenFlow can also be used to perform flow based traffic engineering to direct flows in different paths. Its modular structure in the architecture elements allows for later augmentation towards new service classes as well as a broader range of enforcement means as they are defined and implemented. Service Flow Class Index and Enforcement Database register the available detection, monitoring and enforcement capabilities to be used and referenced in all remaining components of the architecture.
ISAAR is divided into three functional parts which are the QoE Monitoring (QMON) unit, the QoE Rules (QRULE) unit and the QoE Enforcement (QEN) unit. These three major parts are explained in detail in the following chapters.
The interworking with 3GPP is mainly realized by means of the Sd interface [10] (for traffic detection support), the Rx interface (for PCRF triggering as application function and thus triggering the setup of dedicated bearers) and the Gx / Gxx interface [12] (for reusing the standardized Policy and Charging Enforcement Function (PCEF) functionality as well as the service flow to bearer mapping in the BBERF).
Since ISAAR is targeting default bearer service flow differentiation also, it makes use of DiffServ Code Point (DSCP) markings, Ethernet prio markings, MPLS Traffic Class (TC) markings as well as OpenFlow priority changes as available. This is being enforced within the QEN by Gateway and Base Station (eNodeB) initiated packet header priority marking on either forwarding direction inside as well as outside of the potentially deployed GTP tunnel mechanism. This in turn allows all forwarding entities along the packet flow path through the access, aggregation and backbone network sections to treat the differentiated packets separately in terms of queuing, scheduling and dropping.

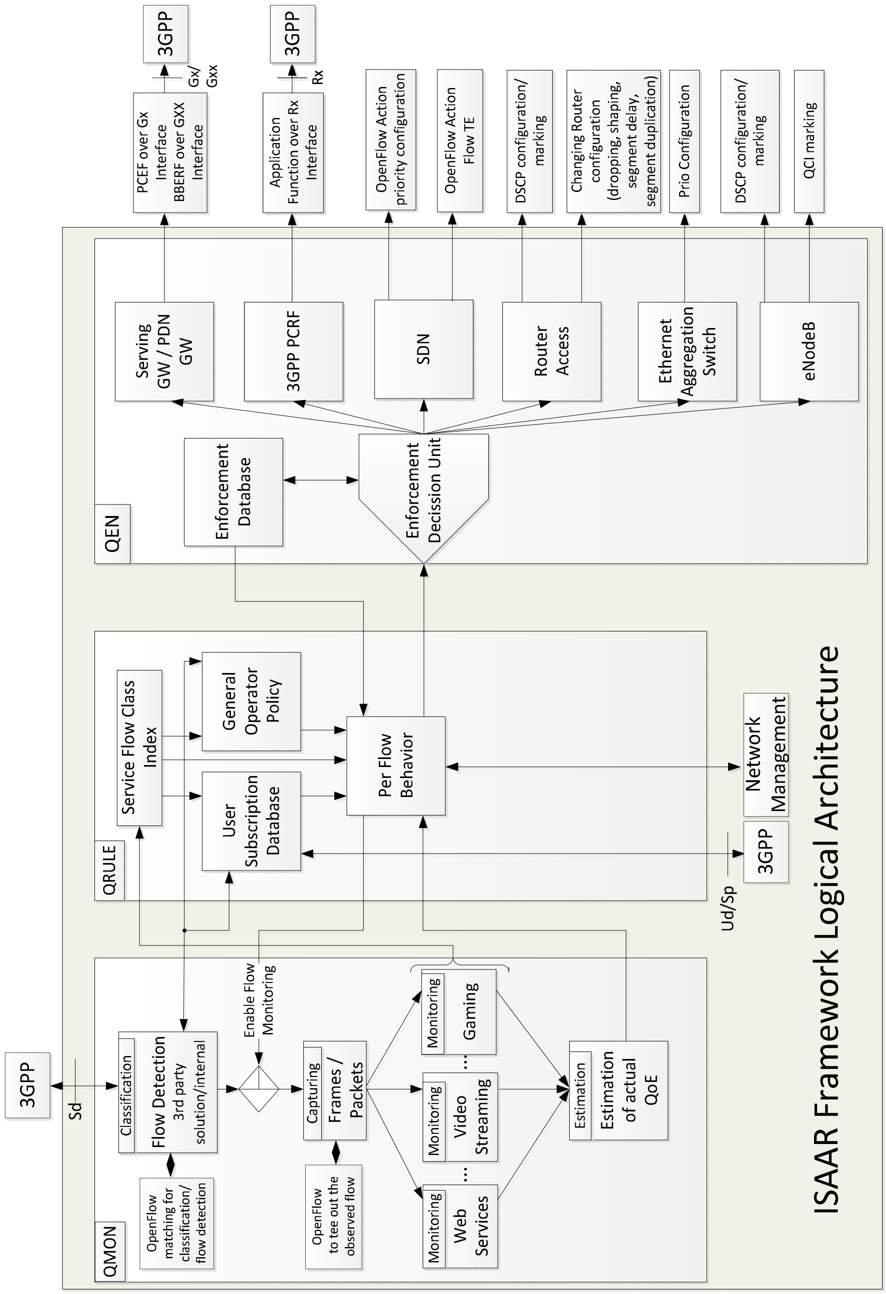

Figure 1: SDN enabled ISAAR framework

The modular structure of the three ISAAR units (QMON, QRULE and QEN) allow for a centralized as well as a decentralized deployment and placement of the functional elements.

4 QoE Monitoring (QMON)

Today's mobile networks carry a mix of different services. Each traffic type has its own network transport requirements in order to live up to the user expectation. To observe the achieved transport quality and its resulting user service experience, network operators need to monitor the QoE of the respective services. Since the quality of service experienced by the user is not directly measurable within the network, a new method is required, which can calculate a QoE Key Performance Indicator (KPI) value out of measurable QoS parameters. The most challenging and at the same time most rewarding service QoE estimation method is the one for video streaming services. Therefore, the paper will focus on video quality monitoring and estimation, not limiting the more general capabilities of ISAAR for all sorts of service KPI tracking.
YouTube is the predominant video streaming service in mobile networks and ISAAR is consequently delivering a YouTube based QoE solution first. Within this YouTube monitoring we are able to detect and evaluate the QoE of MP4, Flash Video (FLV) as well as WebM video in Standard Definition (SD) and High Definition (HD) format.
There are some client based video quality estimation approaches around (e.g. the YoMo application [13]), but we consider such end device bound solutions as being cumbersome and prone to manipulation. Therefore, ISAAR will not incorporate client-side solutions but concentrates on simple, transparent and network-based functionality only.
Some other monitoring solutions follow a similar way of estimation, like the Passive YouTube QoE Monitoring for ISPs approach [14]. However, they are not supporting such a wide range of video encodings as well as container formats.
Another approach is the Network Monitoring in EPC [15] system, but this does not focus on flow level service quality.
The flow monitoring which is used in the ISAAR framework is explained in chapter 4.2 Flow Monitoring). However, before the QoE of a service can be estimated, the associated data flow needs to be identified. Chapter 4.1 Flow Classification) explains the flow detection and classification in detail.

4.1 Flow Classification

The ISAAR framework is meant to work with and without support of an external Deep Packet Inspection (DPI) device. Therefore it is possible to use a centralized DPI solution like the devices provided by Sandvine [16]. For unencrypted and more easily detectable traffic flows the cheaper and more minimalist DPI algorithm which is built in the ISAAR framework can be used. In the first demo implementation, the build in classification is limited to TCP traffic, focussing on YouTube video stream detection within the operator's network. Extended with SDN support there is a third possibility: given the proper configuration, the matching function from OpenFlow could be used to identify the supported service flows within the traffic mix.
In the centralized architecture the flow detection and classification is most suitably done by a commercial DPI solution. In this case the QoE monitoring units have to be informed, that a data stream was found and the classification unit has also to tell them the data stream specific "five tuple". Contained in the five tuple are the source and

destination IP address as well as the source and destination port and the used transport protocol. The QoE measurement starts, as soon as the flow identification information (five tuple) is available.
Due to the new SDN features provided by OpenFlow it is not only possible to identify specific data flows within the Internet. OpenFlow is also capable of teeing out a stream which matches a specific pattern. Thereby, the QoE estimation could be distributed to different monitoring units e.g. depending on the specific Internet application. OpenFlow disposes the right flows to the right monitoring unit.

4.2 Flow Monitoring

In the ISAAR framework the flow monitoring is application specific, i.e. for each service, which should be monitored, a specific measurement algorithm has to be provided. Our current implementation comprises the YouTube Video QoE estimation. It works transparently and independently from the user's end device. Therefore, no tools have to be installed and no access on the end device has to be granted. Our QoE estimation method relies on video stalling events and their re-buffering timings as a quality metric for the video QoE instead of fine grained pixel and block structure errors. To determine the number and duration of re-buffering events it is necessary to comprehend the fill level of the play out buffer at the client, but without access to the end device QMON has to estimate the fill level out of the accessible TCP information within the operator network. Note, that focusing on YouTube video incurs TCP encoded HTTP streaming transport. The detailed description of the method can be found in [17] and [18]. Three variants of the method exist - an exact method, an estimation-based method and a combination of the two.

4.3 Location aware monitoring

Due to the fact that it is probably not possible to measure all streams within an operator network, a subset of flows has to be chosen either randomly or in a policy based fashion. For example, the samples could be drawn based on the tracking area the flow goes to. If it is possible to map the eNodeB cell IDs to a tracking area, the samples also can be drawn in a regionally distributed fashion. With that, it could be decided whether a detected flow is monitored or not due to the respective destination region. Over the time, this sample selection procedure can shift the policy focus to regions with poor QoE estimation results in order to narrow down the affected regions and network elements.

5 QoE Policy and Rules (QRULE)

In this chapter the QoE Policy and Rules entity of the ISAAR framework is presented. The QRULE gets the flow information and the estimated QoE of the corresponding stream form the QMON entity. It also contains a service flow class index in which all measurable service flow types are stored. The enforcement actions for the required flow handling are determined based on information from the subscriber Database and the general operator policy. Also the enforcement database within the QEN is taken into account. Combining all this information the QRULE maps the KPIs to the Per Flow Behaviour (PFB) for each data stream managed by ISAAR. PFBs are defined by appropriate marking of packets and frames. Each PFB has to be specified. Table 1 shows an example of PFB settings for video streaming, voice traffic and Facebook traffic.

Table 1: Per Flow behaviour settings (example)

Media Type	Key Performance Indicator	IP DSCP	OpenFlow Actions	Ethernet Prio	MPLS Traffic Class	3GPP QCI	Action
Video	Buffer Level in Sec. Th1 < t < Th2	CS5 101 000	set normal priority	101	101	6	Mark in S/P-GW and eNodeB with high priority
	Buffer Level in Sec. t < Th1	"Expedited Forwarding (EF)" 101 110	Change path + set high priority	111	111	4	Mark in S/P-GW and eNodeB with highest priority
	Buffer Level in Sec. Th2 < t	"Best Effort (BE)" 000 000 or even "Lower Effort (LE)" 001 000	set low priority	000	000	9	Mark in S/P-GW and eNodeB with default priority or even start dropping packets
Voice	Delay in ms	EF 101 110	Choose best path + set high priority	111	111	4 & 1 or 2	Mark in S/P-GW and eNodeB with highest priority or even Create dedicated bearer with QCI 1 or 2
Facebook	Page load time	CS5 101 000	Choose best effort path + set normal priority	101	101	6	Mark in S/P-GW and eNodeB with high priority
…							

For video streams three possible PFBs (corresponding to three different markings) are provided. These PFPs depend on the buffer fill level. In the example (Figure 2) two buffer fill level thresholds are defined: th1 = 20 seconds and th2 = 40 seconds. If the QoE is poor, i.e. the video buffer fill level is below threshold 1 (t < th1), the EF class (101110) should be used. If the fill level is between threshold 1 and 2 (th1 < t < th2) a DSCP value like CS5 (101 000) should be chosen, because the video QoE is sufficient. Finally if the fill level exceeds threshold 2 (th2 < t) a DSCP value with a lower priority like BE (000 000) or LE (001 000) is taken, so that other flows might get preferred access to the resources.

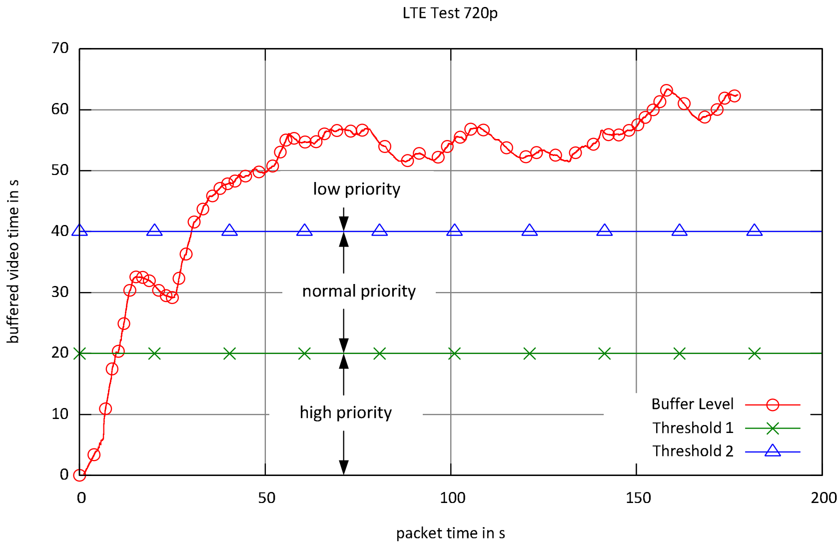

Figure 2: Per flow behaviour dependent on the buffer fill level (YouTube example)

QRULE also decides which kind of marking is deployed depending on the networking technology. It is possible to apply IP DiffServ, Ethernet priority, MPLS traffic class marking and QCI tunnel mapping for GTP. The rules unit has to ensure that there are no oscillating effects in the network. Oscillating could occur on flow level if one flow that is lifted up in priority causes quality impairments for the neighbouring flows. Thus, the second flow will also require enforcement actions, which in turn causes the first one to deteriorate again. To overcome this effect QRULE has to consider which flows were manipulated and in which location they are. Continuous action triggering is an early indication for such race conditions, which results in QRULE dampening of enforcement actions. That is, the transport impairment are such, that ever increasing priority is simply not solving the issue. Oscillating could also occur not only on flow level but on local area level within the network. Thus regional impairment mitigation should not cause increased levels of impairments in neighbouring regions. If this is being detected by location aware QMON, QRULE should also dampen enforcement actions. Close interworking of ISAAR with network management systems fosters this detection of oscillation situations and provides vital information for root cause analysis. If the majority of the traffic would need to be precedented in priority, ISAAR has simply hit its limitation.

If there are OpenFlow enabled switches within the network it is also possible to influence the priority of the frames belonging to a critical flow by changing the OpenFlow Actions for that stream. As these mechanisms are often used in combination, there must be a consistent mapping between them. This mapping is also performed by the QRULE. Further details on the mapping can be found in [19].

For future investigation ISAAR is prepared to incorporate the interworking of GTP and MPLS LSPs in a transparent fashion. Further details on the interworking can be found in [20].

6 QoE Enforcement (QEN)

The third functional block in the ISAAR framework is the QoE Enforcement (QEN) where the flow manipulation is performed. For data streams with estimated low QoE QRULE changes the PFBs and QEN reacts accordingly by applying suitable mechanisms to influence the transmission of the involved data frames or packets.

One possibility to influence the data transmission is to use the PCRF/PCEF and trigger the setup of dedicated bearers via the Rx interface.

A second option is to deploy layer 2 and layer 3 frame/packet markings. Based on these markings a differentiated frame/packet handling (scheduling, dropping) is enforced in the network elements which are traversed by the frames/packets (per hop behaviour). The marking is realized via IP DiffServ, Ethernet priority, MPLS traffic class priority and QCI for GTP tunnels. In case a consistent marking scheme across all layers and technologies is ensured by the QRULE entity, the QEN does not need to change the existing configuration of the network elements.

In the case of a mobile network with GTP tunnelling the marking has to be performed within the GTP tunnel as well as outside. The outside marking enables routers to apply differentiated packet handling also on GTP encapsulated flows without requiring a new configuration. For IPsec encrypted GTP the marking also has to be included into the IPsec header to avoid per hop decryption/encryption. The inner and outer IP markings are set in downstream direction by the SGW/PGW and in upstream direction by the eNodeB based on the flow information (five tuple) and the PFB obtained from QMON. During handover the five tuple and the PFB are automatically transferred to the new eNodeB that is known from the Mobility Management Entity (MME).

As a third option - in case that the predefined packet handling configuration of the routers should not be used - the ISAAR framework is also able to perform a fully automated router configuration [21]. With that, the QEN may explicitly change the router packet handling behaviour (e.g. packet scheduling and dropping rules) to influence the flows.

With the SDN approach there is a fourth possibility to influence data flows by using OpenFlow features. For example, the priority of a flow can be changed in the forwarding configuration directly in an OpenFlow switch action list configuration. Furthermore, flow-specific traffic engineering could be realized. In order to use the OpenFlow features for flow enforcement ISAAR is connected to the control interfaces of the SDN enabled switches.

7 Summary

The ISAAR framework presented in this paper addresses the increasingly important quality of experience management for Internet based services in mobile networks. It takes the network operator's position to optimize the transport of packet flows belonging to most popular video streaming, voice, Facebook and other web services in order to satisfy the customer's service quality expectations. The framework is aware of the 3GPP standardized PCC functionality and tries to closely interwork with the PCRF and PCEF functional entities. However, 3GPP QoS control is mainly based on

dedicated bearers and observations in today's networks reveal that most Internet services are carried undifferentiated within the default bearer only.
ISAAR therefore sets up a three component logical architecture, consisting of a classification and monitoring unit (QMON), a decision unit (QRULE) and an enforcement unit (QEN) in order to selectively monitor and manipulate single service specific flows with or without the standardized 3GPP QoS support. This is mainly achieved by priority markings on (potentially encapsulated) service flow packets making use of the commonly available priority and DiffServ capabilities in layer two and three forwarding devices. In the case of LTE networks, this involves the eNodeBs and SGWs/PGWs for selectively bidirectional marking according to the QRULE determined service flow behaviour.
More sophisticated mechanisms for location aware service flow observation and steering as well as direct router respectively OpenFlow switch configuration access for traffic engineered flow routing are optionally available within the modular ISAAR framework.
Due to the strong correlation between achieved video streaming QoE and customer satisfaction for mobile data services, the high traffic volume share of YouTube video streaming services are tackled first in the on-going ISAAR implementation activity. An optimized network-based precise video QoE estimation mechanism is coupled with automated packet flow shaping and dropping means guided by a three level play out buffer fill level estimation. This way, a smooth play out with reduced network traffic demand can be achieved. To prove the functionality of the network based video QoE estimation a demonstrator has been implemented which is capable of offline packet trace analyses from captured traffic as well as real time online measurements.
Since ISAAR is able to work independently of 3GPP's QoS functionality, it can be used with reduced functionality in any IP based operator network. In such setups, the service flow QoS enforcement would rely on IP DiffServ, Ethernet priority and MPLS LSP traffic class marking as well as SDN based flow forwarding only.

8 References

1. The OpenFlow Switch Specification. Available at http://OpenFlowSwitch.org.
2. IBM; OpenFlow: The next generation in networking interoperability; 2011
3. Sandvine: Global Internet Phenomena Report; 2011
4. 3GPP: TS 23.203 Policy and Charging Control Architecture. 3GPP standard (2012); http://www.3gpp.org/ftp/Specs/archive/23_series/23.203/23203-b60.zip
5. Ekström, H.: QoS Control in the 3GPP Evolved Packet System. In: IEEE Communications Magazine February 2009 pp. 76-83. IEEE Communications Society, New York (2009)
6. I Balbas, J. P., Rommer, S., Stenfelt, J.: Policy and Charging Control in the Evolved Packet System. In: IEEE Communications Magazine February 2009 pp. 68-74. IEEE Communications Society, New York (2009)
7. Ma, K. J., Bartos, R., Bhatia, S., Naif, R.: Mobile Video Delivery with HTTP. In: IEEE Communications Magazine April 2011 pp. 166-175. IEEE Communications Society, New York (2011)

8. Oyman, O., Singh, S.: Quality of Experience for HTTP Adaptive Streaming Services. In: IEEE Communications Magazine April 2012 pp. 20-27. IEEE Communications Society, New York (2012)
9. Ouellette, S., Marchand, L., Pierre, S.: A Potential Evolution of the Policy and Charging Control/QoS Architecture for the 3GPP IETF-Based Evolved Packet Core. In: IEEE Communications Magazine May 2011 pp. 231-239. IEEE Communications Society, New York (2011)
10. Alasti, M., Neekzad, B., Hui, L., Vannithamby, R.: Quality of Service in WiMAX and LTE Networks. In: IEEE Communications Magazine May 2010 pp. 104-111. IEEE Communications Society, New York (2010)
11. Sterle, J., Volk, M., Sedlar, U., Bester, J., Kos, A.: Application-Based NGN QoE Controller. In: IEEE Communications Magazine January 2011 pp. 92-101. IEEE Communications Society, New York (2011)
12. 3GPP: TS 29.212 Policy and Charging Control (PCC) over Gx/Sd reference point. 3GPP standard (2011);
13. Wamser F., Pries R., Staehle D., Staehle B., Hirth M.: YoMo: A YouTube Application Comfort Monitoring Tool; March 2010
14. Schatz R., Hossfeld T., Casas P.: Passive YouTube QoE Monitoring for ISPs. 2nd International Workshop on Future Internet and Next Generation Networks (Palermo, Italy): June 2012
15. Wehbi B., Sankala J.: Mevico D5.1 „Network Monitoring in EPC", Mevico Project (2009-2012)
16. Sandvine Incorporated ULC: Solutions Overview. (2012); http://www.sandvine.com/solutions/default.asp
17. Rugel S., Knoll T. M., Eckert M., Bauschert T.: A Network-based Method for Measurement of Internet Video Streaming Quality; European Teletraffic Seminar Poznan University of Technology, Poland 2011; http://ets2011.et.put.poznan.pl/index.php?id=home
18. Knoll T.M., Eckert M.: An advanced network based method for Video QoE estimation based on throughput measurement; EuroView 2012; http://www.euroview2012.org/fileadmin/content/euroview2012/abstracts/05_04_abstract_eckert.pdf
19. Knoll T. M.: Cross-Domain and Cross-Layer Coarse Grained Quality of Service Support in IP-based Networks; http://archiv.tu-chemnitz.de/pub/2009/0165/
20. Windisch, G.: Vergleich von QoS- und Mobilitätsmechanismen in Backhaul-Netzen für 4G Mobilfunk; 2008
21. Eckert M.: Analyse und automatisierte Konfiguration klassenbasierter Paketvermittlung; 2010