ISAAR
(Internet Service quality Assessment and Automatic Reaction) a QoE Monitoring and Enforcement Framework for Internet Services in 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 within increasingly "Internet Protocol (IP)" based mobile networks. The "3rd Generation Partnership Project (3GPP)" standard based procedures allow for such service differentiation by means of dedicated "GPRS Tunnelling Protocol (GTP)" tunnels, which need to be specifically setup and potentially updated as the mixture of client initiated service consumption changes. The ISAAR (Internet Service quality Assessment and Automatic Reaction) framework augments existing quality of service functions in mobile 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. Chapter 7 gives an overview of the required signalling procedures and interfaces followed by a summary and outlook chapter 8.

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

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 is starting from the service generation, covering potentially several transport entities and finishing 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 potentially many forwarding networks as well as from the end device capabilities and load situation during the result processing and output. More insight can be gained 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 quality observed 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 Internet service provider 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 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 success.

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 "Long Term Evolution (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 [1] for instance shows, that only "Hypertext Transfer Protocol (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)" [2]. The Figure 1 depicts the logical architecture and shows, that 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 should be 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 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 [3]. Nine "QoS Class ID (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.

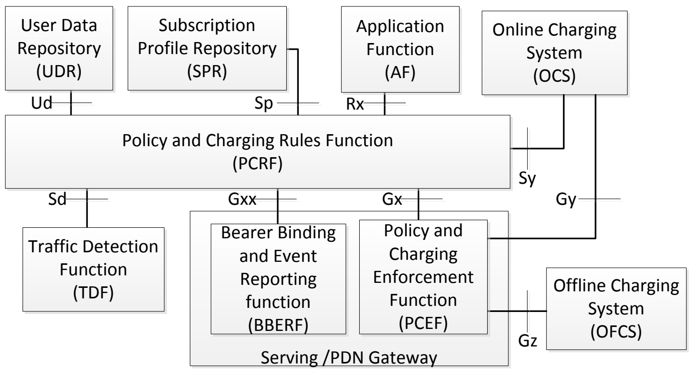

Fig. 1. 3GPP PCC logical architecture after [2] and [4]

Non-IMS based ordinary Internet services, most notably video streaming services, have a high impact on customer satisfaction and overall provider service experience. Therefore, current 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 [1]), which 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 [5].

There are many approaches found in the literature, which address specific services and potential enhancements. "HTTP Adaptive Streaming Services (HAS)" [6] 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. [7]). 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 “Worldwide Interoperability for Microwave Access (WiMAX)” and LTE networks [8] and the „Session Initiation Protocol (SIP)” based “Next Generation Network (NGN)” QoE Controller concept [9] 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 within single bearers without PCRF support as well as 3GPP inclined flow treatment triggering dedicated bearer setups using the Rx interface towards the PCRF. 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 ISAAR Framework has the logical architecture as shown in figure 2. The framework architecture is 3GPP independent but closely interworks with the 3GPP PCC. This independent structure generally allows for its application in non-3GPP mobile networks as well as in fixed line networks also. 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 potentially the “Multiprotocol Label Switching (MPLS)” layer . 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 [10] (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 “Differentiated Services (DiffServ) Code Point (DSCP)” markings, Ethernet prio markings as well as MPLS “Traffic Class (TC)” markings 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. No matter whether the entities are switches or routers.

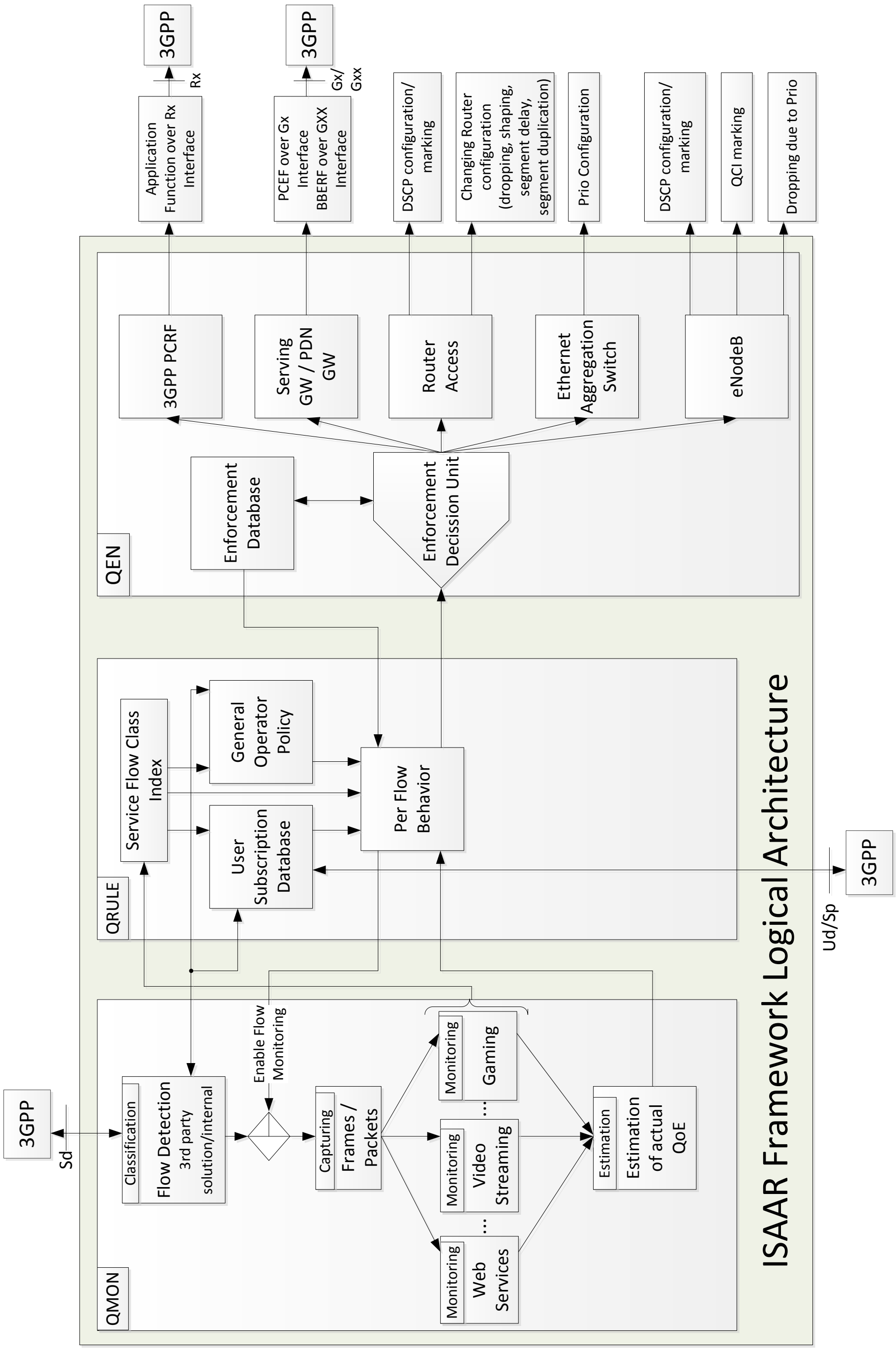

Fig. 2 ISAAR Framework

The modular structure of the three ISAAR units (QMON, QRULE and QEN) allow for a more or less decentralized deployment and placement of the functional elements. Given the common network topology of today’s mobile networks as shown in figure 3, the placement of ISAAR components can be done on the potential locations (1) to (6).

QoE enforcement is the prominent functionality, which could profit the most from a distributed and harmonized deployment right from the access (1) into the core (5). It could also be deployed even behind the core towards the network interconnection to the public Internet. The QRULE unit seems to be sufficiently deployed in a centralized fashion - most likely number (5). The monitoring unit QMON is the most difficult element for placement decision since this becomes a trade-off between service flow route pinning and the processing performance of the QMON device(s). Positioning QMON in (5) gives the advantage, that all traffic to and from the mobile node needs to go through this single point allowing for the complete monitoring of all exchanged service flow packets. However, the interface speed in this central location will become faster, which might require to decentralize the monitoring functionality into the aggregation or even access network part. GTP or MPLS tunnelling could still provide full packet view along a single path, but mobility effects need to be considered for this distributed detection and monitoring ISAAR mode of operation.

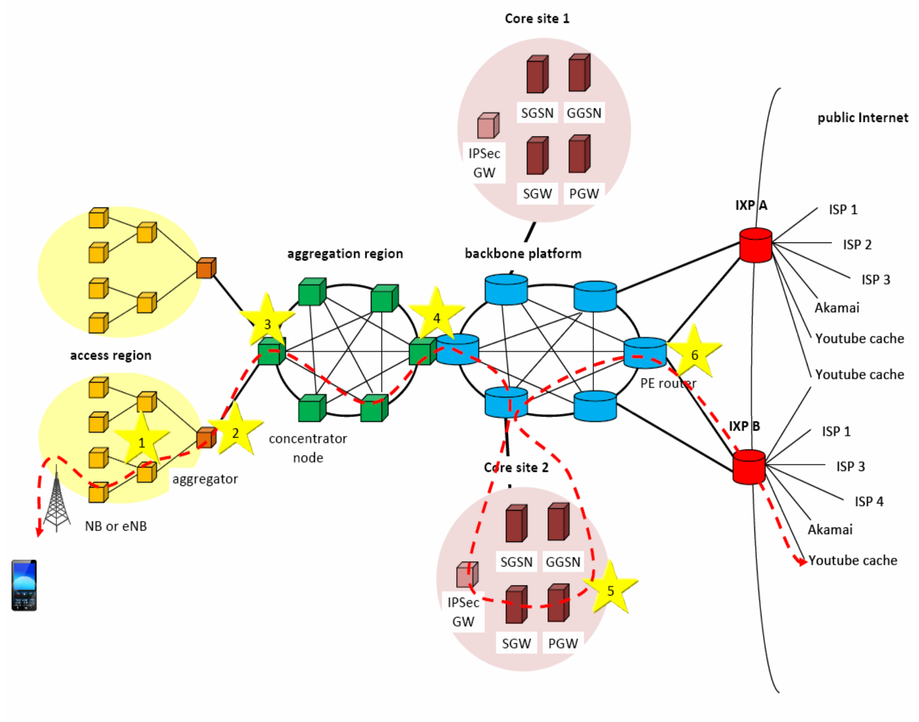

Fig. 3 today’s common network topology of mobile networks

4 QoE Monitoring (QMON)

Today's mobile networks carry a mix of different services. Each traffic type has its own requirements to meet the expectation of the user. The Internet Service Provider wants to satisfy the needs of their customers. Therefore the monitoring of the QoE of the users is necessary. Since the end user's quality of experience of a service is not directly measurable, a network based 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 as well as "Flash Video (FLV)" in "Standard Definition (SD)" and "High Definition (HD)" format.

There are some client based video quality estimation approaches around (e.g. the YoMo application [11]), 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, network-based functionality only.

Some monitoring solutions follow a similar track, like the "Passive YouTube QoE Monitoring for ISPs" [12] and "Network Monitoring in EPC" [13] system, but rely on "Self Organizing Networks (SON)" features only.

The flow monitoring which is used in the ISAAR Framework is explained in chapter 4.2. However, before the QoE of a service can be estimated, the associated data flow needs to be identified. Chapter 4.1 explains the flow detection and classification in detail.

4.1 Flow Classification

The ISAAR Framework is meant to work with and without support by an external "Deep Packet Inspection (DPI)" device. Therefore it is possible to use a centralized DPI solution like the professional devices provided by Sandvine [14]. For unencrypted and more easily detectable traffic flows, it is possible to use a cheaper and more minimalist DPI algorithm which is provided within the ISAAR Framework. The two possibilities could be seen in figure 3. For a distributed solution, the DPI nodes could be located on location (1) to (6), in a centralized case, location (5) or (6) have to be chosen. In a distributed classification architecture, the classification load could be managed by each node. In a first demo implementation, the classification is limited to "Transmission Control Protocol (TCP)" traffic, focussing on YouTube video stream detection within the traffic mix.

In the centralized architecture the flow detection and classification is most suitably done by a commercial DPI solution, in the demonstrator a Sandvine PTS8210 is used.

In this case the measurement nodes have to be informed, that a data stream was found and the classification unit has also to tell them the “five tupel”. Contained in the five tupel are the source and destination IP address as well as the source and destination port, the last information element is the used transport protocol. The measurement starts, as soon as the node gets the identification information of the flow.

4.2 Flow Monitoring

The flow monitoring within the ISAAR Framework is application specific. For each service, which should be monitored, there has to be a specific measurement algorithm. The first part of the monitoring section is the Video QoE estimation (e.g. for YouTube) that was presented at the EuroView 2012 [15], [16]. Like all for the framework planned measurement algorithms the video estimation is a network based algorithm. The advantage is that they are working transparently and fully independent from the user’s end device. Therefore, no tools have to be installed and no access on the end device has to be granted.
The approach presented is focusing on video stalling events and their re-buffering timings as a quality metric for the 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. Focusing on YouTube video incurs TCP encoded HTTP streaming transport. The detailed description of our method can be found in [15] and [16]. It contains 3 variants of estimation methods - an exact method, an estimation method and a combination of these.

4.3 Location aware monitoring

Due to the fact that it is probably not possible to measure all streams within a provider network a subset has to be assigned in a random way. But the distribution of the samples could be mapped to the tracking areas. So it is possible to draw a random set of samples which is normal distributed to all tracking areas. If it is also possible to map the eNodeB cell “Identifications (IDs)” to a tracking area, it becomes possible to draw the samples in a regionally distributed fashion. With the knowledge of that it could be decided whether a detected flow is monitored or not due to the respective destination region. If there are enough samples within the destination area of the flow, further flows will not be selected for measurement. If there are no or few measurements in this area, the flow would be observed.

5 QoE Policy and Rules (QRULE)

In chapter 5 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. In interaction with the user subscriber

Database and the general operator policy, where the operator's policy for each service and the information for what service a user has subscribed is stored, the flow behaviour is appointed. Also the enforcement database within the QEN, which is explained in chapter 6, is taken into account. In combination with all this information the QRULE maps the KPIs to the forwarding and routing rules for each data stream managed by ISAAR. The "Per Flow Behaviour (PFB)" is implemented by marking of packets and frames. Therefore the each PFB has to be specified. Table 1 shows an example of PFB configuration settings for e.g. video streaming, voice traffic and Facebook traffic.

Table 1. Per Flow Behaviour table

Media Type	Key Performance Indicator	IP DSCP	Ethernet Prio	MPLS Traffic Class	3GPP QCI	Action
Video	Buffer Level in Sec. Th1 < t < Th2	CS5 101 000	101	101	6 (or 4)	Mark in S/P-GW and eNodeB with high priority
	Buffer Level in Sec. t < Th1	"Expedited Forwarding (EF)" 101 110	111	111	1	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	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	111	111	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	101	101	6	Mark in S/P-GW and eNodeB with high priority
…						

In the video section are three possible modes which are depending on the buffer fill level calculated in the QMON. According to the information from QoE monitoring different markings are chosen. In the example shown in figure 5 the two buffer fill level thresholds are defined to th1 = 5 seconds and th2 = 25 seconds. If the QoE is poor, that means the video buffer fill level is below Threshold 1 (t < th1), the EF class or the equivalent class of the other technologies is used to improve the video QoE. Lies the fill level between Threshold 1 and 2 (th1 < t < th2) a DSCP value like CS5 (101 000) should be chosen, because the QoE is ok and needs not to be treated in a special way. For the third case if the fill level exceeds Threshold 2 (th2 < t) QRULE has to choose a DSCP value with a lower prioritization (like BE 000 000 or LE 001 000), so the freed resources could be occupied by other flows.

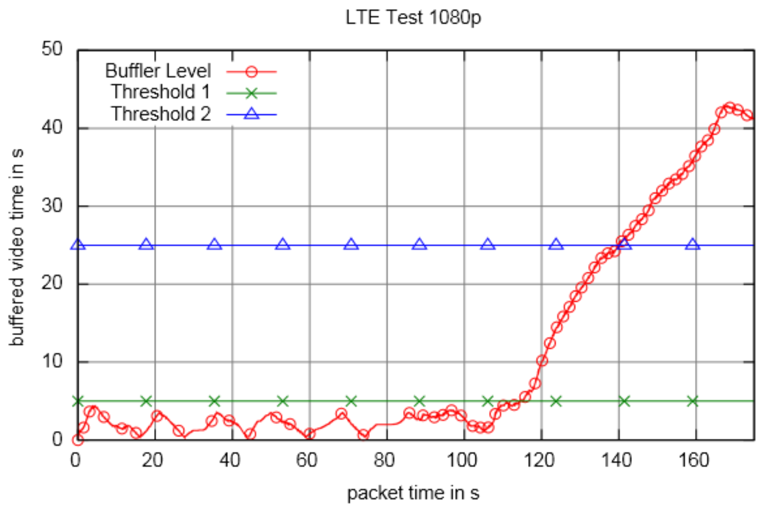

Fig. 4 Per flow Behaviour dependent on the buffer fill level in a YouTube example

QRULE also decides which kind of marking is deployed depending on the available technology. So it is possible to use the DSCP marking for IP routing, Prio for Ethernet forwarding, the MPLS class for “Label Switched Path (LSP)” switching and the QCI tunnel mapping for 3GPP. Due to the reason that these mechanisms are used in combination in provider networks, there must be a consistent mapping between them. This mapping is also done by the QRULE. Further details on the mapping can be found in [17].

For future investigation ISAAR is prepared to incorporate the interworking of GTP and MPLS LSP tunnels in a transparent fashion. Further details on the interworking can be found in [18].

6 QoE Enforcement (QEN)

The third function block in the ISAAR Framework is the QoE Enforcement. In this block the flow manipulation is done. For example if there is an internet service data stream which is estimated with a low QoE then the QEN has to react and e.g. prioritize the flow. To do this we assume some methodologies to influence the transmission of the involved data frames or packets. One possibility is to take advantage of a PCRF/PCEF with dedicated bearers where it is applicable and trigger the setup via the Rx interface.

The second method we propose to be located within the eNodeB and the “Serving

Gateway/Packet Data Network Gateway (SGW/PGW)". It is based on layer 2 and 3 marking within the GTP tunnel as well as outside. How the marking is transferred from inside the GTP to outside is discussed in detail in chapter 5. With the GTP outside marking the stream can be prioritized over other streams along the forwarding and routing path using commonly available priority and DiffServ mechanisms. So the stream is preferentially handled by the network elements without any new configuration within those elements. The marking has to be done by the SGW/PGW for the downstream and the eNodeB has to mark the upstream packets. To be able to mark all packets of a flow, the flow information (five tupel) must be transmitted from the QMON block to all involved elements in this case the SGW/PGW and the eNodeBs which the flow will pass through. This could e.g. be realized via the "Mobility Management Entity (MME)" and the flow state could automatically be transferred during handover using the standard user state procedure.

The outer tunnel marking has also to be transferred to the "Internet Protocol Security (IPSec)" so that the priority of an encrypted stream can also be changed. Therefore the DSCP value of the outer tunnel IP packet header is set to the same value. This leads to the possibility to handle encrypted traffic streams without decryption. The network element need not to know what kind of flow is within the tunnel they only handle the IP packets by their DSCP configuration.

The marking mentioned above has to be done within IP, Ethernet Priority, MPLS Priority and the QCI classes. To get a comprehensive QoE Enforcement, the flow has to be classified and measured in the QMON, the priority of that flow has to be determined by the QoE Ruler and then the QoE Enforcement takes place and does the marking. But the marking has to be valid in the whole operator's network, where the mentioned priority markings were used in a mixed way. To overcome that, the markings have to be converted to each other which is also explained in detail in chapter 5. Marked packets or frames could be routed or forwarded with operator configured per hop behaviour, which results in different queuing and dropping strategies. With this option the QEN does not have to change the router or switch configuration within the operator's network. Because such priority based forwarding and routing is handled automatically by prio enabled Switches and "Label Switch Routers (LSRs)" as well as DSCP enabled routing devices.

But the ISAAR Framework should be also able to do a fully automated router configuration [19]. For that case the enforcement function optionally changes the router behaviour for a specific flow. Thus the packet dropping is influenced. To do this the QEN has to be aware of the actual router configuration and has to change it in a way that the stream's needs are met. After the configuration is changed it must be transferred back onto the router. There are two conceivable ways how the QEN could be aware of the actual router configuration. The first one is to read the information from the router in at first. But with this option the signalling load is increased and it takes a lot of time. A second approach is that the router configuration of all routers is known in a configuration database. In this variant ISAAR only changes the configuration send it to the corresponding devices and save the new configuration in this database.

7 QoE Framework Signalling and Interfaces

The ISAAR Framework consists of different entities and devices. The framework itself could be distributed across the whole provider network. For example the QMON and QRULE could be located in the PGW/SGW and the QEN could be distributed over eNodeBs and routers within the network. To ensure the function of ISAAR there must be a information exchange between the different functional parts. The reasons why the communication between the distributed entities is necessary will be shown in the following example.

If the flow detection is located within the SGW/PGW the information about a detected flow (e.g. the five tupel) has to be transmitted to the policy enforcement entities which could be located in the eNodeBs. The results out of the measurement in the eNodeBs have to be processed in the central QRULE to decide how a stream has to be treated. The Information about the treatment (e.g. handling of the different DSCP values determined by the QEN) could also be transmitted back to the routers and eNodeBs. Also the QRULE must announce the DSCP marking. If the DSCP treatment is statically configured within the routers the QRULE does not have to share this information and the signalling load is reduced.

Maybe there are some other entities within the concept e.g. a KPI collector which gathers the information measured by the probes within the eNodeBs and creates a statistical summary to minimize the transmitted data. Also due to the distributed character of ISAAR it has to be ensured, that all entities know from each other. For that reason all probes, collectors and other distributed entities need to be configured accordingly.

In order to enable the more sophisticated location aware monitoring, ISAAR has to map the cell ID to a specific IP and also to a specific probe address. Therefore the framework needs access to the MME. With the help of the MME it is possible to locate a specific cell ID and together with the former mapping from cell ID to probe to IP address, the localization of a flow destination, the probe in charge for this location can be found. This way, ISAAR can delegate the measurement load into the respective area.

In case an observed and treated flow gets lost for any reason ISAAR has to inform all involved framework parts. Therefore it has to be signalled, that the measurement of the lost stream should be stopped and also all DSCP rules and markings.

The ISAAR Framework has some replicated functionalities with the PCC architecture from 3GPP [2]. Therefore, it is possible to use some of the PCC functional blocks if they are available. The ISAAR Flow Detection could be aligned with 3GPP's “Traffic Detection Function (TDF)”, the User Subscription Database has a similar functionality as the “Subscription Profile Repository (SPR)” and some parts of the QEN from ISAAR could also be done from the BBERF, the PCEF and the “Application Function (AF)”.

8 Summary

The ISAAR (Internet Service quality Assessment and Automatic Reaction) 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 customers and their service quality expectation. 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 entities. 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 configuration access for traffic engineered flow routing are optionally available within this modular 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 ongoing 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.

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 only.

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