End-to-End Quality-of-Service Support in Next Generation Networks with NSIS

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***Abstract*—Future telecommunication networks are likely designed along the Next Generation Network (NGN) framework of the ITU-T. End-to-end Quality-of-Service support—independent from underlying transport-related technologies—is one of the fundamental requirements of NGNs. This paper presents an overarching QoS control architecture that is based on the IETF's Next Steps in Signaling framework. It provides a detailed discussion of how the NSIS approach fits into the NGN architectures, its coupling to the IP Multimedia Subsystem, and possible migration paths from centralized to more distributed approaches. Advantages of using NSIS as part of an NGN-based QoS architecture are pointed out and implementation results for parts of a proposed NGN architecture are presented.**

I. INTRODUCTION

The Internet's great success during the last decade was primarily based on the significantly increased use of multimedia applications, such as Voice-over-IP, video streaming, or online gaming. The Internet architecture, though providing a very robust, so-called best-effort packet-based service, was however, not designed to provide inherent support for Quality-of-Service (QoS). In order to react promptly on upcoming user's service demands, future telecommunication networks are likely to be designed along the ITU-T's *Next Generation Network* (NGN) framework, which operates all-IP-based but provides end-to-end QoS and supports mobility of end-users at the same time. Therefore, one of the key principles of NGNs is fixed and mobile convergence where services are to be used independently from the underlying transport technology.

Within the standardization bodies of the 3rd Generation Partnership Project (3GPP) the *IP Multimedia Subsystem* (IMS) was introduced as an architectural framework for an all-IP-based network that provides standardized interfaces and QoS control schemes by defining dedicated service and control functions. IMS is often mentioned to be used as an enabling technology for NGNs.

This paper focuses on an architecture to provide end-to-end Quality-of-Service (QoS) control for overarching technologies and networks. The relation and interaction with IMS as well as the ETSI/TISPAN *Resource and Admission Control Sub-System (RACS)* are described. The chosen approach shows a higher flexibility and better extensibility for QoS support in NGNs than the traditional strongly IMS-based QoS control schemes. We start with a brief overview of NGNs and the Next Steps in Signaling (NSIS) framework, which is developed within the Internet Engineering Task Force (IETF), before we discuss related work in the context of this paper. Afterwards, we present our approach towards an end-to-end Quality-of-Service supporting architecture that is based on the NSIS framework. Finally, we refer to some implementation results for parts of the proposed architecture.

II. BACKGROUND AND RELATED WORK

NGNs, as defined in ITU-T Recommendation Y.2011 [1], are packet-based networks that provide telecommunication services and broadband QoS enabled transport technologies. An important aspect of NGNs is the independence of underlying transport technologies in order to provide QoS enabled services. Moreover, NGNs aim at supporting all kinds of mobility and convergence between fixed and mobile networks.

The *transport stratum* of the NGN architecture comprises access functions that are related to managing end-user access to the network as well as access transport functions that deal with the transportation of information of the access network such as QoS mechanisms like traffic conditioning, queuing, and scheduling. The core network must provide core transport functions to differentiate the quality of data transport, edge functions, and especially transport control functions in order to perform access and reservation control in the network, including Network Attachment Control Functions (NACF) and Resource and Admission Control Functions (RACF).

The *service stratum* on the other hand includes service and control functions for registration or authorization as well as service user profile functions that combines user details into profiles. *IMS* [2], [3] is an architectural framework for an all-IP based network that offers standardized interfaces and SIP-based services to subscribers. Session control and resource reservation in IMS is provided by the *Call Session Control Function (CSCF)*. Application functions (AF) realize the necessary service- and application-specific logic, e.g., for Voice-over-IP or Video Streaming services.

It is important to note that IMS is designed to support specific services. Therefore, an application-level service request that is signaled via SIP has to be mapped into corresponding transport level resource demands by the Resource Management Function (RMF). However, these services must be supported by the application and by the network operator. Though IMS provides a lot of flexibility for introducing and supporting new services, an end user cannot directly request generic QoS support for yet unknown or unsupported applications, i.e., application independent QoS support.

A. Next Steps in Signaling Framework

The IETF's NSIS working group was created in response to some inherent deficiencies of the already present signaling protocol RSVP, such as missing mobility support, offering QoS as the sole signaling application, and the restriction of performing receiver-initiated reservations only [4].

The NSIS framework follows a two-layer approach by separating the transport of signaling messages from the signaling application itself. The signaling application's logic in NSIS is carried by an *NSIS Signaling Layer Protocol* (NSLP) such as QoS NSLP [5] which can be used for the purpose of QoS resource reservations along a data path.

The defined QoS NSLP is independent of any particular QoS model, such as IntServ (Integrated Services) or DiffServ (Differentiated Services). It supports both, sender- and receiver-initiated reservations from end-to-end, from edge-to-end, or even from edge-to-edge, by working as a proxy on behalf of an end device. NSIS is also flexible enough to offer both network- and user-initiated QoS. RMF related information is carried in a separate object, called QSPEC, effectively specifying the requested resources.

B. Related Work

The Daidalos project [6], [7] aimed at seamlessly integrating heterogeneous network technologies at the network access and providing end-to-end QoS mechanisms at the same time. QoS support is considered both at IP layer and link layer.

A QoS Broker performs admission control and manages network resources in a domain. An access network has its own local QoS Broker (Access Network QoS Broker) which leads therefore to a more centralized resource management approach. A QoS client uses a lightweight RSVP client for explicit QoS signaling. QoS unaware IP legacy applications are supported by access routers performing dedicated functions ranging from advanced router functions for connection tracking and DiffServ marking to QoS signaling. Implicit signaling uses DiffServ Codepoints set by the application, explicit signaling is done by application signaling protocols, e.g., SIP or RSVP. It is, however, not detailed how QoS parameters will be derived from the flow's data packets. Furthermore, more distributed control architectures, where resource admission control functions are integrated into *Universal Access Nodes* (UAN), are not considered in Daidalos.

Mobile devices and wireless access technologies are very well considered in Daidalos. MobileIPv6 is used for mobility management together with extensions like FastMobileIPv6 in order to achieve seamless handovers. Even though resources are checked before a handover is initiated, they are not pre-reserved. Therefore, resource availability for the entire handover process cannot really be ensured. Furthermore, RSVP—which is used for explicit QoS reservations—is not able to support mobile clients very well.

Besides Daidalos different projects aimed at defining QoS architectures that should cope with the requirements of tomorrow's networks. While the WEIRD project's [8] goals focused on an integrated support for QoS, resource and access management, and AAA, the approaches were designed solely in the context of the WiMAX technology. Within the EuQoS project [9] an architecture was introduced, that should provide end-to-end Quality-of-Service support over heterogeneous networks. Even though the HyPath-based approach already used a modified NSIS framework, the defined QoS architecture was not considered to be integrated into the NGN architecture as with our approach. Within the CHEETAH project [10] a wide-area GMPLS network was introduced in order to provide a circuit-switched end-to-end architecture with a strong focus on optical networking technologies. CHEETAH uses RSVP-TE as signaling solution to establish end-to-end circuits upon a user's request. The presented framework was, however, not designed to fulfill the requirements of an NGN and hence does not provide means to handle mobile end users for instance. A related project, called DRAGON [11], provides a framework for dynamic resource allocation in GMPLS based optical networks and uses RSVP-TE as signaling solution. Although this framework was designed to provide end-to-end connectivity across heterogeneous networks and interdomain-wide, it was not designed to be compliant with NGN specifications.

III. AN OVERARCHING QOS CONTROL ARCHITECTURE

In order to define an overarching QoS Control Architecture, appropriate QoS mechanisms in the data path must be specified. In accordance with the ITU-T's recommendation of NGNs, we consider IP to be the natural choice to overcome the heterogeneity—it basically runs over nearly any link technology and provides a single interface to transport protocols and applications. In contrast to QoS mechanisms that are solely link-layer based (e.g., Ethernet MAC frame marking) QoS mechanisms at the IP layer allow for using a fine grained control of IP flows (e.g., policing and accounting) and QoS mappings. Additional link layer QoS mechanisms such as different service classes may nevertheless be used in addition, or even required for first mile access, e.g., radio access networks. As a least common denominator we assume DiffServ mechanisms to be used as a scalable solution in the IP layer.

Since reliable service guarantees require admission control and resource reservation procedures, signaling resource reservation requests must be performed on-demand by the *User Equipment* (UE). Basically, two possibilities exist: either the resource reservation request is derived from the IMS related signaling and is *pushed* to the RACS or the UE signals the resource reservation request on its own directly at the IP layer, which results in the admission decision being *pulled* by the transport layer from the RACS. The latter approach has the advantage that QoS resources can be requested also for non-IMS based applications and as such being more flexible and future-proof.

A. NSIS and IMS Interworking

The NSIS framework can be used in order to provide overarching end-to-end QoS support. Within this approach a UE signals directly its demands for IP resources to network layer control. Using NSIS as the primary QoS control mechanism in an NGN architecture offers some significant advantages. A central aspect herein is that resource reservation requests are completely independent from any specific applications and are therefore not bound to SIP-applications only. This approach promises maximum flexibility towards services that are to be used on top of those reservations, especially regarding yet unknown future applications and services. Furthermore, NSIS is closer related to the actual data path than any application level signaling, thus it is possible to react much faster upon changes within the data path. In Section V the advantages of using NSIS in the context of this work are discussed in more detail.

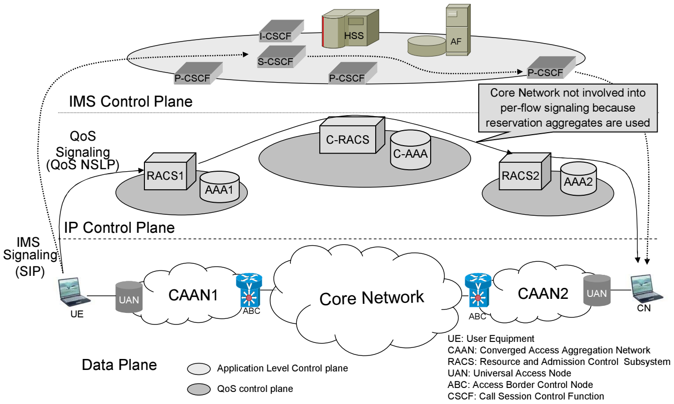

Figure 1. Architecture view with NSIS and IMS Signalling

Figure 1 gives an overview showing the different planes for QoS and IMS and a rough overview of signaling paths for an ISP's domain. First, the UE performs application level signaling at the IMS control plane in order to request IMS-based services. After service-specific parameters have been negotiated with the Correspondent Node (CN), the UE may request QoS support from the transport stratum by using QoS NSLP. RACS entities are usually involved for performing resource-based, policy-based admission control, or both. For scalability reasons, reservation aggregation concepts are applied in Converged Access Aggregation Networks (CAAN) and especially in the core network domain. Since on the one hand the requested QoS may depend on the application-level negotiation, e.g., available and supported codecs, and on the other hand the codec choice may depend on the available resources, both signaling procedures are mutually interdependent. In order to break the circular dependency between codec negotiation and resource reservation an integration with IMS signaling is achieved according to the negotiation solution described in RFC 3312 [12] and RFC 5432 [13].

Figure 2 illustrates how IMS and QoS Signaling are coupled. In the first phase, the SIP negotiation is started to exchange the session descriptions and hence the codecs to be used. The fact that this SIP signaling will be carried out via use of P-CSCFs in different domains is not shown in Figure 2. In Phase 2, the UE starts QoS signaling to the RACS. It is assumed that there exist aggregate reservations across the core network so that usually there is no need to signal for QoS per end-to-end flow in the core network. Therefore, signaling can be performed directly between RACS1 and RACS2 of the CAANs. After resources have been reserved the third phase will finish the IMS session setup by using the SIP Update method. On success the callee's phone will ring and he can start a conversation with guaranteed QoS.

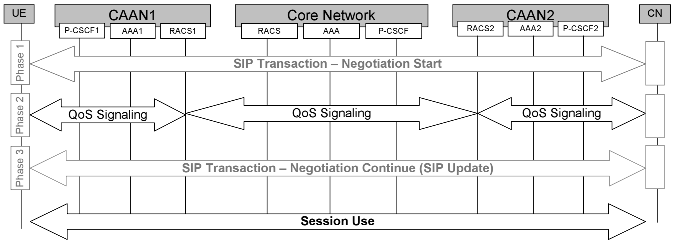

Figure 2. Interworking of NSIS and IMS Signaling

B. Deployment Variants and Migration Strategies

The proposed QoS architecture can be used with and without IMS, which is compliant with the RACS requirements (described in Section IV), i.e., use of a separate QoS signaling protocol offers application-independent QoS support. The approach can be coupled with network-initiated QoS schemes, i.e., pure IMS-based QoS control can co-exist with NSIS-based solutions. NSIS-unaware end nodes can be integrated by using proxies. Interoperability will be increased by using an open standard like QoS NSLP. This also allows using different QoS models that realize QoS enforcement in the data path.

Regarding the possible capabilities and different locations of functional entities, the proposed QoS control architecture is open to a diverse set of available deployment strategies. Thus, a more centralized approach may be easier to deploy at first, where only a few components need to be NSIS-capable. A scenario with more distributed control can be introduced as soon as more and more network components are NSIS-capable. For the remainder of this section the UE is supposed to be NSIS-aware, i.e., it is capable of signaling for QoS on demand using QoS NSLP. However, due to the possibility of using the QoS NSLP proxy mode for non-NSIS capable UEs, even this assumption may be partially relaxed in early deployment scenarios.

The first presented approach addresses the situation when none of the UANs is supposed to be NSIS-aware but rather a *centralized* RACS—which provides a *domain-wide* RACF and Policy Decision—supports NSIS. The UE's QoS NSLP resource reservation request may be either directed towards its flow destination, i.e. hit eventually the UAN in which case the UAN would have to redirect all NSIS messages to the RACS, or signaling from the UE must be performed path decoupled directly towards the RACS. The latter case can be accomplished by using an Explicit Signaling Target Message Routing Method as proposed in [14] and requires discovery of the RACS's address (e.g., by using DHCP, Router Advertisements or DNS resolution). Upon reception of a QoS NSLP request the RACS contacts the AAA server for policy-based admission control, performs local admission control, and forwards the request downstream towards the CN. The CN on the other hand generates an NSLP Response upon which the RACS adapts pre-reserved resources depending on finally negotiated values and forwards the response to the UAN, which in turn installs traffic profiles locally.

In another approach all UANs are assumed to support NSIS and a central RACS supports the Diameter Quality-of-Service Application [15]. The AAA entity may be integrated into or separated from the RACS. In case it is separated, Diameter QoS should be used between both entities. Regarding the signaling, the UE sends a QoS NSLP request path-coupled towards the UAN. The UAN performs policy-based admission control and contacts the RACS upon success. The RACS contacts the AAA server for policy-based admission control and pre-reserves resources in case of acceptance. After that, the QoS NSLP request is forwarded along the path towards the CN, a Response is generated by the CN and resource reservations are adapted by the RACS, before the UAN may install traffic profiles.

The final approach applies to a setup where all UANs are NSIS-aware and the RACF is distributed along the UANs. In this scenario, each UAN is therefore supposed to support QoS NSLP and the Diameter QoS Application, but also provides a local RACF and is able to install profiles locally. The RACF itself is not meant to work centralized anymore, hence it uses an internal RACF and uses the Diameter QoS Application for requesting policy-based admission control from a central AAA/PDP entity. Like in the last approach mentioned above, the UE signals a QoS NSLP request towards the UAN which contacts the AAA server for policy-based admission control on behalf of this request. It is important to note, however, that the UAN should use aggregate reservations towards the egress router. After the admission request is forwarded further along the path towards the CN and probably through aggregate reservations, the Response is generated by the CN upon which the UAN may adapt its pre-reserved resources to the actually negotiated values and install traffic profiles.

IV. THE RACS FRAMEWORK

This section discusses how the chosen NSIS-based approach matches the NGN RACF framework of the ITU-T [16] and the RACS framework of TISPAN [17].

Figure 3 shows the RACF architecture as defined in Y.2111 [16]. The CPE (Customer Premise Equipment, same as UE in our terminology) signals a service request to the service control functions (e.g., AF/P-CSCF of IMS). The path-decoupled signaling variant is currently not considered by [16]. With respect to QoS capabilities three different CPE types are defined:

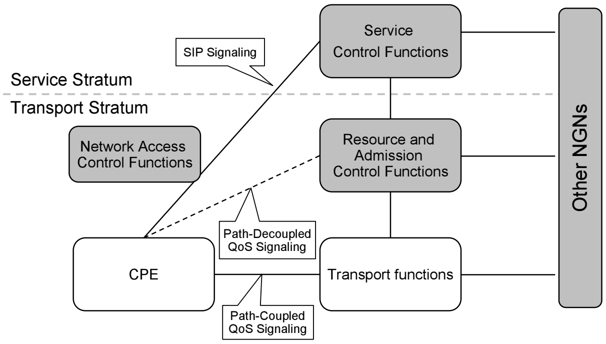

Figure 3. RACF within the NGN architecture

- *Type 1* — CPE has no QoS negotiation capability, so it cannot directly request QoS resources.
- *Type 2* — CPE has QoS negotiation capability at the service stratum, e.g., by using QoS parameters in SIP/SDP.
- *Type 3* — CPE is able to perform QoS signaling at the transport stratum (e.g., the CPE supports RSVP-like or other transport signaling).

Types 1/2 and Type 3 allow different possibilities on how to perform QoS control. Section 6 of [16] mentions two different resource control modes:

- *Push mode*: RACF performs authorization and resource control decisions based on policy rules and instructs transport functions to enforce the policy decision.
- *Pull mode*: RACF performs an authorization decision based on policy rules and—upon request of the transport functions—re-authorizes the resource request and responds with the final policy decision for enforcement.

Pull mode is strongly dependent on a Type 3 CPE. Note, that the NSIS-based QoS architecture proposed in Section III fulfills this constraint by using an NSIS-aware UE that is a CPE of type 3. Furthermore, Y.2111 Section 6 contains a description of two scenarios, one for push mode and one for pull mode. The scenarios therein are somewhat simplified since usually the QoS requirements can only be determined by a Service Control Function (SCF) when a first SIP negotiation happened from end to end. Thus, both communication partners must have negotiated at least the codec that is going to be used as being proposed by RFC 3312 [12]. Only if this information is available, the actual and correct amount of resources to be requested can be determined reliably. Policy-based admission control and resource reservation can then be performed subsequently.

Thus, even if we have a non-Type3 CPE, the 'Push Operation' can only happen after the codecs have been negotiated and the resource reservation was successfully established. As a consequence, RFC 3312 should also be applied for Push Mode. Otherwise, it is not clear for which CPE codec resources should be reserved, due to a circular dependency where the chosen codec may depend on the available resources and the allocated resources depend on the chosen codec. The only admission control decision that may be performed without contacting the other side is a rather static one based on service policies, e.g., admission depending on whether the user is allowed to use the service at all.

A. ETSI/TISPAN RACS Functional Requirements

At first we repeat some relevant requirements regarding the RACS functional architecture according to ETSI Standard [17]. The RACS authorizes appropriate transport resources and defines L2/L3 traffic policies that are enforced by the bearer service network elements and sets the bearer transport function with network-level attributes, i.e., QoS, accordingly.

Furthermore, the RACS shall not be specific to any AF or service subsystem, offer services to AFs that reside in different administrative domains, hold a logical view of the different transport segments within its control (includes last mile and aggregation network), or receive topology and resource information for the transport segments under its control. Note, that the RACS should not be IMS-specific and should be usable for other subsystems as well, which is well met by our NSIS-based QoS control architecture.

B. NSIS-capable CPE

Figure 4 illustrates how NSIS-based signaling works in pull mode:

- Step 1: SIP signaling Phase 1 according to RFC 3312, i.e. codec negotiation.
- Step 2: The CSCF signals a resource request to the RACS. The SPDF within the RACS may check service policy and provide an authorization token that allows requesting a resource reservation.
- Step 3: The UE maps the negotiated codec to a QoS request (QSPEC) and transmits it via QoS NSLP. The QoS NSLP RESERVE message contains the authorization token of Step 2.
- Step 4: The QoS Request is passed upwards to the RACS by using the *Re* interface, in order to pull the corresponding admission decision. The A-RACF passes the authorization token to the SPDF via *Rq* along with the QSPEC, upon which the SPDF performs the policy-based admission control and returns the result to the A-RACF.
- Step 5: The A-RACF sends the result back to the UAN. Resources are pre-reserved in the A-RACF but still need to be committed when the QoS reservation response comes back from the other end. QoS Signaling can then be continued from the UAN.
- Step 6: If the end-to-end QoS signaling, negotiation, and reservation process was successful (not shown), the resources are finally committed to the A-RACF and traffic policies are pushed into Resource Control Enforcement Function (RCEF).

A further variant does not depend on the authorization token that is passed during the application level signaling. Instead, an authentication token from the NASS is used to authenticate the UE. The policy-based admission control is checked by the SPDF. This is depicted in Figure 5.

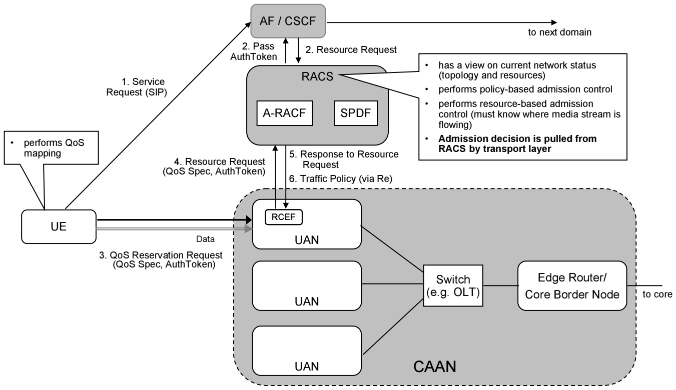

Figure 4. NSIS-based signaling, pull mode

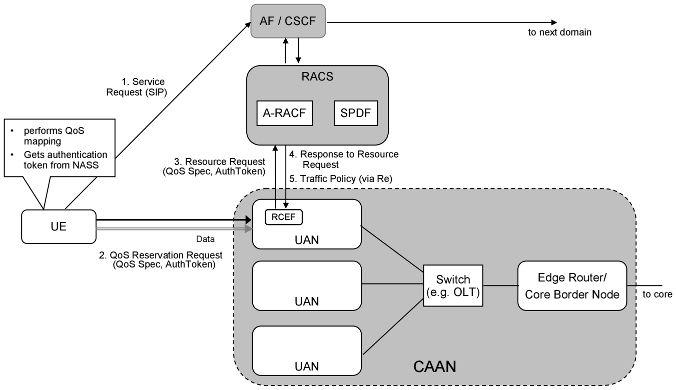

Figure 5. Native QoS reservation request via NSIS QoS NSLP

V. DISCUSSION AND EVALUATION

The main benefits of using QoS signaling initiated by the end-system (UE, CPE) are the greater openness, flexibility, and extensibility of the architecture. Thus, it will also work with non-IMS applications and non-IMS networks. The following list provides a discussion of the benefits in more detail:

- *Openness, Flexibility, Extensibility* — A separate QoS signaling allows requesting QoS support from the network transport stratum for any application, especially also non-SIP-based/non-IMS applications. Thus, the native application independent QoS procedure will also work for yet unknown future applications as long as their QoS requirements can be described.
- *Increased Interoperability* — The solution will also work with parts of the network where no AF/CSCF/IMS is available. This includes core network domains without IMS as well as non-IMS operators transporting the data.
- *QoS Model independence* — NSIS supports different models for QoS provisioning in the data path and thus heterogeneous domains.
- *Closeness to Data Path* — NSIS signaling has a tighter coupling to the data path and to the network resources than application level signaling protocols like SIP. According to current knowledge this is of advantage for mobile nodes and for detecting route changes. SIP signaling,

i.e. a Re-INVITE with an updated c-attribute in the SDP part, will usually be triggered by a link layer indication for handover. However, the node movement will not be visible in case the IP address is unchanged. The path-coupled variant of NSIS provides a native detection if the data path changes: signaling message will automatically follow the new path if the flow path changes.

- *More efficient resource usage* — Reservation aggregation at transport level is based on QoS classes and thus application independent. Although a mapping of SIP media descriptions to QoS requirements and finally QoS classes is possible, aggregation can only be performed for services whose mapping to QoS classes is known. That means that non-IMS applications could be mapped to QoS classes that are also used for QoS-based IMS sessions, i.e., the same aggregate reservation could be used for IMS and non-IMS services.
- *Real end-to-end QoS* — As the UE is involved into the QoS negotiation, local resource conditions may be considered during the resource admission phase.

Parts of the proposed QoS control architecture were implemented and evaluated. First, due to the focus on FMC we verified the eligibility of the NSIS QoS NSLP with respect to its applicability in mobile networks [18]. In this work, we used MobileIPv6 for mobility management and QoS NSLP to initiate QoS reservations between the UE (also the Mobile Node – MN) and the CN. MobileIPv6 events were used as triggers for emission of QoS NSLP messages in order to update or adapt already existing reservations accordingly. Thus, we integrated mobility extensions into the freely available NSIS-ka implementation [19] and tested all possible combinations for reservation setup—the MN could be either sender or receiver as well as initiator or responder. Our evaluation showed that even in case of hard handovers a reservation could be restored fairly quick, with only a marginal extra latency compared to non-mobile reservation setup duration.

Besides mobility scenarios, we evaluated a user-based integrity protection mechanism for QoS NSLP signaling messages. This allows for a per-user and per-session authorization that is important for proper accounting of QoS-based services. An existing proposal was extended by adding a lightweight HMAC signature per user, which possesses good scalability properties with respect to the number of users and data flows that request QoS support. Details to this evaluation can be found in [20] and are not presented for brevity here.

VI. CONCLUSION

The presented QoS control architecture uses QoS NSLP of the NSIS framework for end-system oriented QoS signaling of resource reservation requests. The chosen approach fits well into the overall NGN and RACS framework of the ITU-T and ETSI/TISPAN and offers lots of benefits compared to pure IMS-based approaches. The gained flexibility regarding QoS support for future and even non-IMS based applications is of particular importance for NGNs.

ACKNOWLEDGMENT

Part of this work was supported by Deutsche Telekom Laboratories and T-Systems within the ScaleNet project, which was funded by BMBF (Federal Ministry of Education and Research).

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