Quality of Service Negotiation in support of post-Download User Sessions

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***Abstract*—Software-defined radio enables mobile devices to upgrade their capabilities through over-the-air software download. Next-generation mobile networks are expected to support radio software download to SDR-enabled equipment, dynamic selection of radio access technologies, and online switching to new operational modes during user sessions. This contribution exploits a cohesive control and management framework for serving reconfigurable devices; the primary functional entities of this logical model are described, along with a physical realization in Beyond 3G networks. In order to assure end-to-end quality of service for user traffic generated upon radio software download and equipment reconfiguration, a novel negotiation control scheme for the core network is proposed. As reconfigurability will gradually stretch from end-user devices to base stations and, in the long term, to interior network elements, the considered mechanism employs an end-to-end label capturing key reconfiguration indicators. The paper raises the issue of self-awareness of network nodes on the end-to-end data path established after a reconfiguration and discusses the challenge of providing transparent operation over so-called reconfiguration-ignorant nodes.**

***Index Terms*—beyond 3G, negotiation, network control, quality of service, reconfigurability, software radio**

I. INTRODUCTION

Over-the-air software download to reconfigurable devices is an important utility for operators and manufacturers. The major benefits from the introduction of Software-Defined Radio (SDR) technologies are remote fault management, service differentiation through the upgrade of device capabilities, and handover between different air interfaces, with or without service continuity [1] [2].

Advances in SDR and Cognitive Radio (CR) [3] pose new requirements to evolved core network architectures and signalling procedures. Reconfigurability [4] looms as key enabler for All-IP mobile systems and networks Beyond 3G [5] [6], stretching from access and connectivity up to protocols, applications, and services. The Reconfigurability thematic enhances the SDR/CR concept by supporting dynamic spectrum access and on-the-fly over-the-air download of radio software, including new Radio Access Technologies (RATs). In addition, it goes beyond network interworking, encapsulating end-to-end control and management support in order to adapt or upgrade the system (e.g., network elements from source to destination and function relocation), the equipment (e.g., reconfiguration of hardware resources), the service, the application, and the content [7].

The SDR Forum [8] has specified the requirements for downloading radio software to end-user equipment, specifying individual steps for procedures such as discovering the need to download, download setup, capability exchange between the terminal and the network, and actions after the installation of the downloaded software [9]. Furthermore, 3GPP acknowledges that an All-IP network would benefit from the support of reconfigurable radio interfaces in the terminal [10]. Nevertheless, specifications have not incorporated yet mechanisms for the reconfiguration of mobile devices through software download.

The paper is organized as follows: the motivation for an architectural framework and Quality of Service (QoS) negotiation in order to exploit equipment reconfiguration through over-the-air radio software download is explained in the following section. Section III delineates the modelling assumptions and scope of the proposed control and management framework for the coordination of reconfiguration procedures. The key functional entities along with a physical realization in Beyond 3G networks are described in Section IV. The signalling exchange between the reconfigurable terminal equipment and interior network nodes in order to seamlessly support the activation of new radio software is presented in Section V. Conclusions are given in Section VI.

II. MOTIVATION

This contribution extends the SDR Forum software download steps [9] within the context of reconfigurable Beyond 3G mobile networks. Firstly, the paper exploits a cohesive control and management framework, namely the Reconfiguration Management Plane (RMP) [7], which supports operations and notifications in a network-agnostic protocol-independent fashion. Next, the manuscript builds on the derived network architecture in order to propose QoS negotiation actions between the reconfigurable device and interior network nodes. The objective is to guarantee that the user traffic generated as a result of the download and activation of new radio software will enjoy the desired quality of service.

Whereas [9] assumes that the network operator has to forecast and provision sufficient resources on the software download path, this contribution addresses the issue of QoS guarantees in the post-download phase for "golden subscription" users that will immediately initiate new sessions over the downloaded radio software. The need for QoS assurance of forthcoming user sessions stems from the observation that software upgrades may impact the end-to-end network operation. Specifically, *software updates* preclude any additional capabilities or features to be added to the updated software, except operational improvements aiming, for example, at increasing the software stability. Contrarily, a *software upgrade* denotes the addition of new features [11], which may pose further implications on the network operation. For example, the downloading of a new RAT may yield the initiation of radio bearers with increased QoS demands, therefore also affecting the core network segments of the end-to-end data path.

The paper proposes a negotiation framework in which the terminal and the network exchange both capability information and end-to-end state in order to enforce reconfiguration strategies and to guarantee seamless realization of user sessions in heterogeneous network segments (hops or domains). A new identifier that carries SDR-related parameters is introduced in order to capture the impact of terminal reconfiguration on perceived end-to-end QoS of forthcoming user sessions. Such label should be installed on all network elements on the candidate data path for assisting in the admission test, resource reservation, and packet classification procedures following the terminal reconfiguration.

III. Modeling Assumptions

Reconfiguration is envisioned as a set of policy-driven tasks, which includes the ways to efficiently adapt, upgrade, and apply the functionality that an entity supports, to any expected or potential change of its state, situation, and activity. End-to-end reconfiguration necessitates the proposal of coordinated management and control functions that govern the interactions between the involved entities and orchestrate the negotiation, decision-making, and enforcement of mechanisms in a dynamic fashion. The Reconfiguration Management Plane is an expression of an abstract view of a network element or subnet by means of functional entities incorporating specific functionality to realize physical-implementation-independent control, management, and Operations, Administration, and Maintenance (OA&M) tasks [7].

The RMP consists of *plane management modules* and *layer management functions* that cater for reconfiguration-induced control and management tasks, such as reconfiguration services negotiation and session control, provision of reconfiguration policies, and control of software download steps. Legacy management areas are enriched in order to capture reconfiguration-oriented aspects, such as profile and resource management, access and security management, and billing and accounting management. Specifically, the RMP provides a coordinated set of control plane functions that address real-time terminal-initiated reconfiguration and operate on user plane resources. In addition, management plane functions support offline network-initiated scenarios. The RMP plane-based modelling is augmented with layer management functionality, which handles OA&M functions per layer.

The following section provides an overview of the planes and layers comprising the RMP logical model.

IV. The Reconfiguration Management Plane

A. Plane Management Modules

The RMP plane management includes the following modules (Fig. 1): Reconfiguration Management Module (RMM), Software Download Management Module (SDMM), Context Management Module (CtxMM), Policy Provision Module (PPM), Service Provision Module (SPM), Performance Management Module (PeMM), Access and Security Management Module (ASMM), and Billing and Accounting Management Module (BAMM).

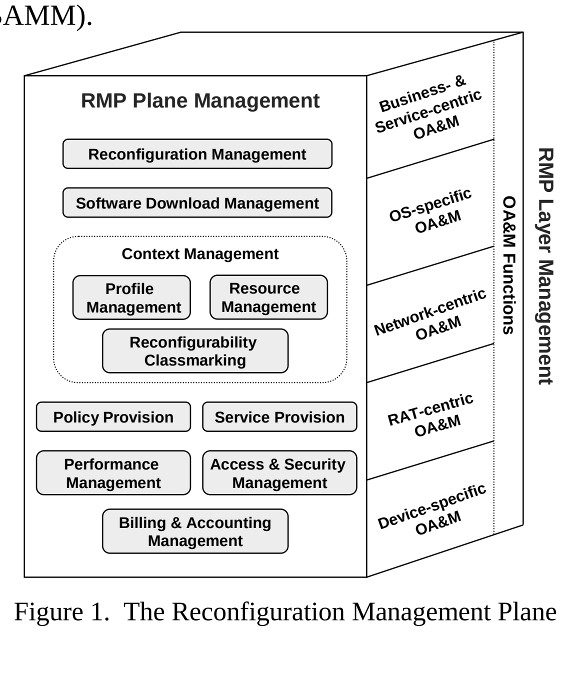


Figure 1. The Reconfiguration Management Plane

The *Reconfiguration Management Module* supervises the end-to-end process by initiating network-originated and coordinating device-initiated reconfiguration commands. The RMM communicates with peer entities in the reconfigurable terminal and in interior network elements for the discovery of available reconfiguration services and for the negotiation signalling aiming at capability exchange prior to network or mode selection.

In the case of scheduled software download, the RMM hands-over the control of the reconfiguration steps after capability exchange to the SDMM. Finally, the RMM undertakes the necessary session management and mobility management context transfer and translation in cases of inter-domain and inter-system handover, e.g., from a 3GPP system to a WiMAX access network.

The *Software Download Management Module* is responsible for identifying, locating, and triggering the suitable protocol or software for download, as well as for controlling the steps during and after the download.

Profile composition and provision is handled by the *CtxMM Profile Management Module (PrMM)*, which manages static and dynamic profile information (user profile; network profile; application/service profile, terminal profile, etc.). In addition, the *CtxMM Reconfigurability ClassMarking Module (RCMM)* assigns and validates the so-called *Reconfigurability Classmark*; this classmark specifies the level of dynamism regarding reconfiguration, depending on the type of reconfiguration requested and negotiated, on the type of software to be downloaded, on business incentives, and on individual or operational chains of stakeholders involved in the reconfiguration process.

The *Policy Provision Module* is the main decision-making entity for reconfiguration, by comprising the entry point for reconfiguration-related system policies. Furthermore, it exploits contextual information and redefines policy rules and reconfiguration strategies. This module produces an up-to-date decision about the feasibility of a reconfiguration as well as respective actions to be triggered. In addition, the PPM caters for inter-domain issues, interacts with Policy Enforcement Points (PEPs) (e.g., the GGSN PEP) and facilitates the mechanics for the differentiation of end-to-end reconfiguration services, as explained in section V.

The RMM, PrMM, RCMM, and PPM modules are directly involved in the negotiation control scheme presented in section V. Details on all plane management modules can be found in [7].

B. Layer Management Functions

Layer management functions are related to the management of resources and parameters in each protocol layer, thus maintaining interfaces to both the control and management planes. The RMP layer management functions are classified to five categories (Fig. 1). The upper three layer management functions manage parameters and resources of software that is agnostic to underlying RATs and devices. Examples include software satisfying business goals, user requirements, operating systems specificities, and network requirements. Business- and Service-centric functions include logs and alarms reported to the user; Operating-System-specific functions embody auditing, testing, and validation procedures after software download; Network-centric functions accommodate traffic estimations. Finally, RAT-centric functions address radio resource management and function partitioning and reallocation, whereas Device-specific functions include remote equipment management and reconfiguration of hardware resources. Details on the RMP layer management functions can be found in [7].

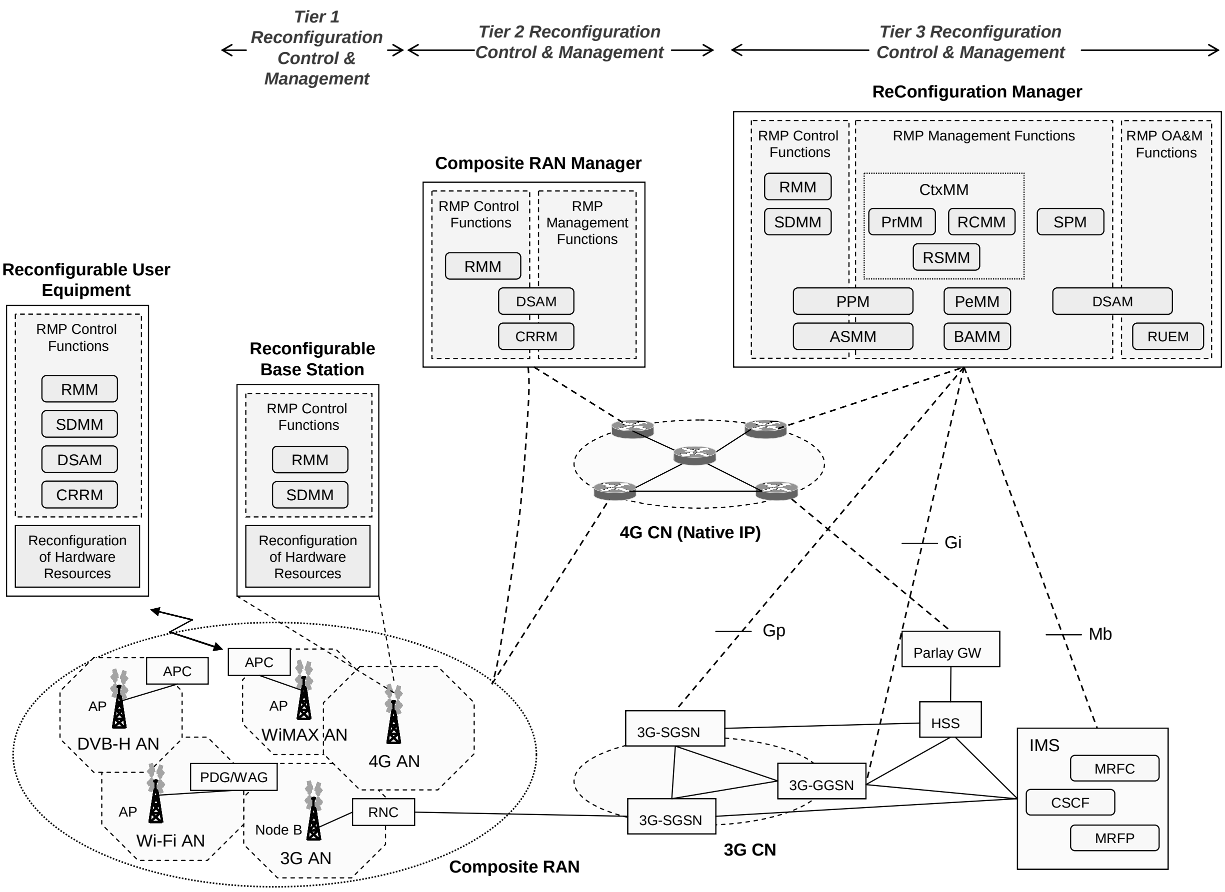
C. Distribution of RMP Functionality in Beyond 3G Mobile Networks

Composite Radio Access Networks (RANs) support a multitude of RATs, with the optimal radio invoked on-demand. Fig. 2 shows composite RAN environments coupled with scenarios of evolved core network architectures. From a hierarchical perspective, the architecture consists of the ReConfiguration Manager (RCM), which is a network element located beyond the network access server (e.g., the GGSN) in the core network domain or in a trusted third party, and the Composite RAN Manager (CRM), which manages a composite RAN, thus being responsible for functions such as Common Radio Resource Management (CRRM) [12] and Dynamic Spectrum Access Management (DSAM) [13].

V. NEGOTIATION SIGNALLING

This contribution envisages the SDR Forum download steps [9] from a broader perspective, as part of a generic reconfiguration process that groups these steps to three phases:

- the *Preliminary Reconfiguration Phase* for information gathering, analysis, and decision making;
- the *Reconfiguration Negotiation Phase* for capability exchange, negotiation, and



3G	Third Generation
4G	Fourth Generation
AN	Access Network
AP	Access Point
APC	Access Point Controller
ASMM	Access and Security Management Module
BAMM	Billing and Accounting Management Module
CMM	Configuration Management Module
CN	Core Network
CRRM	Common Radio Resource Management
CSCF	Call-Session Control Function
CtxMM	Context Management Module
DNPM	Dynamic Network Planning and Management
DSAM	Dynamic Spectrum Access Management
DVB-H	Digital Video Broadcast – Home
GGSN	Gateway GPRS Support Node
GPRS	General Packet Radio Service
GW	Gateway
HSS	Home Subscriber Server
IMS	IP Multimedia Subsystem
MRFC	Multimedia Resource Function Controller
MRFP	Multimedia Resource Function Processor

OA&M	Operations, Administration and Maintenance
PDG	Packet Data Gateway
PeMM	Performance Management Module
PPM	Policy Provision Module
PrMM	Profile Management Module
RAN	Radio Access Network
RAT	Radio Access Technology
RCM	ReConfiguration Manager
RCMM	Reconfigurability ClassMarking Module
RMM	Reconfiguration Management Module
RMP	Reconfiguration Management Plane
RNC	Radio Network Controller
RSMM	ReSource Management Module
RUEM	Remote User Equipment Management
SDMM	Software Download Management Module
SGSN	Serving GPRS Support Node
SPM	Service Provision Module
WAG	WLAN Access Gateway
Wi-Fi	Wireless Fidelity
WiMAX	Wireless Interoperability for Microwave Access
WLAN	Wireless Local Area Network

Figure 2. Functional architecture for Reconfigurable Beyond 3G Mobile Networks

application of reconfiguration-related state information; and

- the *Reconfiguration Realization Phase* for the assurance and fulfilment of reconfiguration via software download.

The stages and steps are described in detail in [14]. This section focuses on the reconfiguration negotiation phase for the case of terminal-initiated software upgrade. During this phase, the terminal and the network are engaged in a loop of exchanging capability information and end-to-end state for enforcing reconfiguration strategies, as well as for guaranteeing seamless operation of user plane sessions in heterogeneous network segments (hops or domains). These facilities can be offered through installation of state information at various network elements.

Fig. 3 charts the steps that comprise the reconfiguration negotiation phase (one iteration shown due to space limitations):

1. The RCM_RMM requests the terminal capabilities (equipment and software capabilities) from its peer entity in the terminal (T_RMM) via the RCM_PrMM.
2. The T_RMM compiles a detailed list of the terminal capabilities and replies to the RCM_PrMM.
3. Based on the reported terminal capabilities, the RCM_RCMM validates (and updates if necessary) the Reconfigurability Classmark.

4. The RCM_RMM is notified about the current terminal capabilities.
5. The RCM_RMM determines the network nodes that are on the data path from the terminal to a list of most frequently accessed external networks. This can be achieved by parsing a list of Access Point Name (APN) fields.
   This step can be undertaken by the terminal as well. However, the network should be responsible for such operation in order to ensure efficient operation in cases of RAN nodes connected to multiple core network nodes [15]. In addition, the details of network topologies should be hidden from the terminal.
6. The RCM_RMM requests the capabilities of these network elements. This step requires communication between the RCM_PrMM and the associated network elements, which may have to be reconfigured as well in order to support potential increased demands due to terminal reconfiguration. These interior network elements are referred to as Network element Reconfiguration Support Functions (N-RSFs) in Fig. 3.
7. All N-RSFs provide their current capabilities. A proxy could also undertake such task on behalf of network domains or subnets.
8. The RCM_RMM asks the RCM_PPM to generate the hereafter called *End-to-end Reconfiguration Label (ERL)* [7] and to apply end-to-end-reconfiguration-related state to transit nodes.

The ERL comprises a spatial-temporal expression of the impact of terminal reconfiguration on perceived end-to-end QoS. Such label is installed on all network elements on the candidate data path for assisting in the admission test, resource reservation, and packet classification procedures. The ERL should be a globally unique identifier (e.g., using hash functions such as SHA-1) incorporating legacy parameters when user traffic traverses 3G networks - e.g., MS Class, IMEI Software Version, Network Mode of Operation, RAN mode, RAT type, MS classmark, CN classmark, Radio access classmark, NITZ (Network Identity and Time Zone) - as well as yet-to-be-proposed identifiers for Beyond 3G networks. These fields should accommodate evolving capabilities of the terminal equipment (e.g., runtime profile), as well as new dimensions of offered network services, such as real-time control of the service flows with merged Flow-Based Charging (FBC) and Service-Based Local Policy (SBLP). SBLP enables IMS and non-IMS Application Functions to control the QoS provided by the GPRS bearer service based on the requirements of the negotiated application services, exploiting the COPS protocol and PDP context modification procedures [16][17]. In addition, self-awareness of reconfiguration capabilities of the network elements on the end-to-end data path (based on the categorization explained in step 13), and the profile of the traversing networks/subnets should be taken into account.

9. The RCM_PPM computes the ERL.
10. The RCM_PPM commands the N-RSFs to apply ERL-related state.
11. Each N-RSF undertakes the task of applying this state information, which may result in intra-element decisions as well as in negotiations with neighbour network elements for the

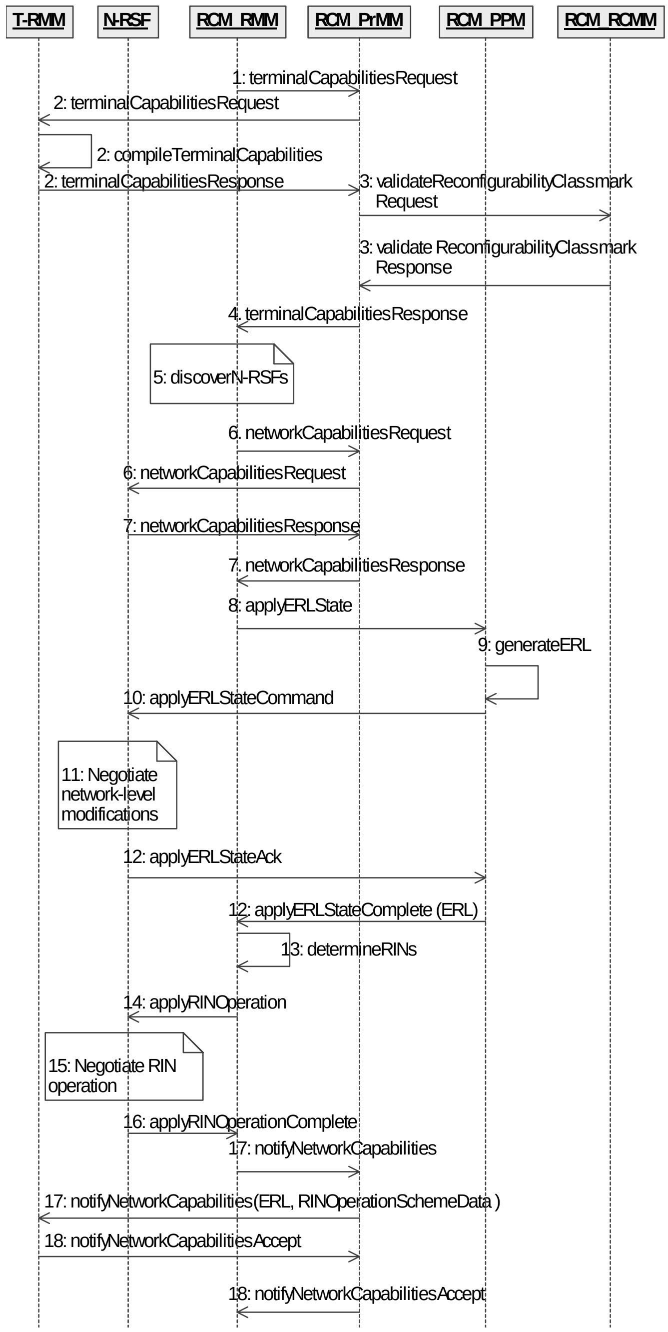


Figure 3. Negotiation signalling

modification of resource-specific parameters (e.g., upgrade of supported bearers and optimal setting of bearer parameters).

It is worth noting that resource reservation actions should not take place at this point. Firstly, the data path has not been established yet and the exact destination endpoint is unknown. Secondly, the decision on the scheme for operation over hereafter-called *Reconfiguration Ignorant Nodes (RINs)* (explained in step 13) affects the resource reservation phase. Finally, it is recommended that such reservations be done on an end-to-end basis.

12. The N-RSFs inform the RCM_PPM about the results of the installation of ERL state.

It is worth noting the necessity to ensure ERL state is accepted by and installed on all network nodes prior to the negotiation and application of any RIN operation scheme explained below.

13. Based on the notifications received in step 12, the RCM_RMM classifies the network elements to three categories [7]:
    - *Reconfiguration-enabled*: A network node with the maximum degree of reconfiguration capabilities.
    - *Reconfiguration-aware RIN*: A node being aware that it can or cannot support software download requirements and subsequent user sessions due to new radio activation (e.g., adaptation of supported resources).
    - *Reconfiguration-unaware RIN*: A node with no capabilities to interpret any reconfiguration signalling. Thus, subsequent user traffic traversing this node is not protected be abnormal download situations.

Steps 14-16 are optional, depending on the framework for the operation over reconfiguration ignorant nodes and or domains/areas.

14. The RCM_RMM commands the N-RSFs to take all necessary actions for operation over RINs. These actions are for further study.
15. A negotiation mechanism employed by the N-RSFs ensures sufficient and efficient operation over the three above-mentioned classes of nodes.
16. The N-RSFs inform the RCM_RMM about the results of applying the RIN operation scheme.
17. The RCM_RMM informs the T_RMM (via the RCM_PrMM) about the network capabilities. This message includes the ERL value. In addition, the algorithm and configuration options for RIN operation should be sent to the mobile device, as well as (part of) data related to network-level modifications originating from ERL state establishment (step 11).
18. Finally, the T_RMM accepts the network configuration and capabilities for the subsequent download steps.

VI. CONCLUSIONS

Commercial realization of end-to-end reconfiguration is expected to be a long-term process. In order to absorb the impact of heterogeneous wireless access on network infrastructures, a novel process for negotiation control was proposed, satisfying the requirement of proactively establishing QoS state for user traffic that is generated upon terminal reconfiguration. The QoS negotiation scheme exploits previous work on an end-to-end reconfiguration control and management framework. From a deployment perspective, the Reconfiguration Management Plane can be introduced either as extension to existing control and management planes or as a new intermediary plane for dedicated reconfiguration-induced tasks, with functional entities distributed to network elements for achieving flexible scenarios and dynamic function relocation. The proposed negotiation procedures can be implemented via SIP/SDP and COPS protocol extensions on top of legacy UMTS PDP procedures. In addition, the QoS NSLP feature of in-call bandwidth modification can be exploited for reservations that are not necessarily end-to-end [18].

In order to accomplish operation over reconfiguration-aware and unaware nodes or domains, the end-to-end reconfiguration label should assist in the initiation, negotiation, and enforcement (packet classification and filtering) of end-to-end operations on the user and control planes. Design issues pertaining to the granularity of such label will be further investigated, including the incorporation of various reconfiguration classes, aiming at diverse service offering within the context of Beyond 3G mobile networks.

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