RSS: The Reconfiguration Support Subsystem for Next-Generation Mobile Networks

Zachos Boufidis, Nancy Alonistioti, and Lazaros Merakos
Communication Networks Laboratory
Dept. of Informatics and Telecommunications
University of Athens, Athens, Greece
E-mail: {boufidis, nancy, merakos}@di.uoa.gr

Abstract-**The technological race of boosting legacy and developing new air-interfaces, recent advancement of core network architectures, and evolution from software-defined and cognitive radio to reconfigurable systems put new complexions on the definition of "next-generation". This contribution envisages Next-Generation Mobile Networks as the class of multi-radio cognitive systems capable of absorbing the heterogeneity of wireless access, with advanced reconfiguration capabilities moved from edges to the core. Inline with 3GPP IMS rationale and ETSI TISPAN design extensions, a unified subsystem for offering reconfiguration services is proposed, adopting a multi-plane and layer-based approach with clear separation of control and management concerns. The paper presents the signalling between the terminal and network elements in the course of an exemplary staged reconfiguration process, and discusses design and deployment advantages when introducing the so-called Reconfiguration Support Subsystem in Beyond 3G portfolios.**

I. Introduction

The concept of "next-generation" spans three converging axes. Standardisation bodies such as 3GPP and IEEE and leading manufacturers have been working on upgrading cellular radio and on new wireless standards. The need to shift core network design in order to exploit the full benefits of IP as mature carrier technology is ever increasing, with emphasis on extensibility, self-management, and ease of interworking with yet-to-be developed protocols. Reconfigurability looms as key enabler beyond Software-Defined Radio (SDR) and Cognitive Radio (CR) [1] [2] that stretches from access and connectivity up to protocols, applications, and services, and pervades the other two constituent elements of "next-generation".

Efforts on the evolution of cellular Radio Access Technologies (RATs) within 3GPP include High-Speed Downlink Packet Access (HSDPA), Enhanced Uplink (E-UL), Multimedia Broadcast/Multicast Service (MBMS), and Super 3G. 3GPP has set the requirements for long-term evolution of the Radio Access Network (RAN), including multi-RAT support, increased spectral efficiency, higher data rates with reduced latencies, and flexible functional split between RAN and core network [3]. On the other hand, IEEE has been developing wireless personal (e.g., 802.15.3a, 802.15.4), local (e.g., 802.11a/g/n), metropolitan (e.g., 802.16a/d/e (WiMAX), 802.20), and regional access networks (e.g., 802.22), with recent proposals for SDR-oriented standards (P1900) and interoperability considerations for handover between heterogeneous networks (802.21). Other proprietary solutions include ArrayComm's i-Burst and Flarion's FLASH-OFDM, offering broadband-like speeds and operating over simpler architectures below IP transport. While there is no 4G standardisation under way, DoCoMo announced in June 2005 1Gbps downlink packet transmission in a field experiment.

The advance of SDR/CR and reconfigurable equipment poses new requirements to core network architectures. The SDR Forum has specified a set of steps for downloading radio software to end-user equipment, catering for issues such as authorisation to download, capability exchange between the terminal and the network, software verification, and in-situ testing [4]. Although complete, this framework needs supplements and fine-tuning when applied to specific architectures such as Beyond 3G networks [5]. On the other hand, Reconfigurability [6] is the collection of technologies for dynamic spectrum access and on-the-fly over-the-air download of new RATs, encapsulating end-to-end control and management support in order to adapt or upgrade the system (e.g., network elements from source to destination), the equipment (e.g., function relocation or reconfiguration of hardware resources), the application, the service, and the content [7].

Since Release 5, 3GPP adopted a session-based core network architecture using the Session Initiation Protocol (SIP). The resulting IP Multimedia Subsystem (IMS) [8] is a unified control and user plane framework, which is considered as the next-generation core network paradigm for service provision to wireless devices. Although 3GPP acknowledges that an All-IP network would benefit from the support of reconfigurable radio interfaces in the terminal [9], specifications have not incorporated yet capabilities for flexible software download aiming at terminal reconfiguration. On the other hand, ETSI TISPAN provides system enhancements to IMS for fixed broadband access. The Next-Generation Network (NGN) Release 1 architecture consists of subsystems for network attachment, resource and admission control, and emulation of legacy systems (PSTN/ISDN), cooperating with the "core IMS" [10].

The principal challenge for next-generation mobile networks is to absorb the disparity of radio standards and to gracefully accommodate end-to-end session control, quality of service negotiation, security and reliability to SDR and CR, while introducing new interfaces both between a plethora of

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devices and networks and between networks. Contrary to 3G, a secondary objective is to move next-generation capabilities and intelligence from edges to the core, fostering IMS facilities for integrating future access technologies/networks [11]. From an operational perspective, the major benefit for operators and application service providers will be in deployment, monitoring, and support of new services over next-generation mobile networks.

In order to address complexity and heterogeneity, this contribution proposes a cohesive subsystem, referred to as Reconfiguration Support Subsystem (RSS), for next-generation mobile networks, adopting a plane- and layer-based approach with clear separation of data, control, management, and Operation, Administration, and Maintenance (OA&M) concerns. The paper is organised as follows: the RSS logical model is presented in Section II, with the following section describing the constituent functional entities. Section IV portrays generic signalling exchange during a staged terminal reconfiguration process. A concluding discussion on the advantages of introducing the RSS in Beyond 3G networks can be found in Section V.

II. The RSS Logical Model

The RSS adopts an innovative multi-plane and layer-based approach. In order to offer reconfiguration-specific functionalities, new vertical planes are proposed, namely the Mode Negotiation Control Plane, the Intermediary Reconfiguration Management Plane, and the Data Switching Sub-Plane (Fig. 1). The control plane in current systems consists of loosely coupled components that operate on some user plane functions. The RSS provides a coordinated set of control plane functions that cater for real-time terminal-initiated reconfiguration, and operate on user plane resources. In addition, management plane functions support offline network-initiated scenarios. The RSS plane-based modelling is augmented with layer management functionality, which handles OA&M functions per layer. An overview of the planes and layers comprising the RSS logical model follows.

A. Vertical Planes

The *Mode Negotiation Control Plane (MNCP)* undertakes control actions for network-initiated reconfigurations requested by the *Intermediary Reconfiguration Management Plane (IRMP)*. Equivalently, it comprises the network point-of-presence and first contact point in the case of endpoint-requested reconfiguration. In general, an endpoint would be, in the short term, the terminal or the base station. In the long term, interior network nodes and/or subnets can be reconfigured, such as routing areas or domains where reconfiguration services can be offered.

The MNCP functional entities initiate and setup *reconfiguration sessions* and *download sessions*. A reconfiguration session allows the RSS to a) discover the option set of software or protocol configurations that can be supported by the terminal, b) grant the permission of the terminal on the planned reconfiguration, and c) schedule the protocol installation. The commencement and coordination of capability exchange and negotiations are integral parts of a reconfiguration session.

A download session determines the pre-fetching steps that guarantee efficient and seamless transport of the target software. In the course of a download session, the *download context* is generated and distributed to all concerned network elements. The download context includes instructions to the endpoint on how to download (e.g., the OMA *download descriptor* [12]), the required network resources, and state information to support the download transfer.

Specifically, the MNCP entities support the following functionalities:

1) Filtering of reconfiguration strategies and policy rules. Reconfiguration strategies describe high-level constraints, such as time zone restrictions defined in the user subscription and roaming selection options specified in inter-operator agreements. Policy rules represent the respective technical limitations, such as the required terminal equipment memory, processing, and energy capabilities.

2) Modus operandi negotiation and transition, which refers to signalling, reasoning, and switching between modes of operation. Whereas SDR and CR envisage dynamic on-the-fly selection, download, and switching between RATs, current 3GPP specifications only consider pre-installed RATs that do not affect the core network. However, even with a well-designed core network, automatic (terminal-initiated) software downloads may cause traffic fluctuations, which may turn the core network into a bottleneck. Hence, there should be intelligence high in the network hierarchy to guarantee that the transition to a new mode is as seamless as possible for the operator's network.

3) *Distribution of download context* during a download session. This functionality is explained in Section IV.

The IRMP lies between the MNCP and the traditional management plane. The IRMP coordinates the MNCP functional entities in network-initiated reconfigurations, such as a performance alert. Specifically, the IRMP accommodates reconfiguration-specific *plane management* functionality, including management of vendor-initiated software upgrades, remote management of reconfigurable devices, and policy-based QoS management (provisioning of QoS policies and QoS monitoring of reconfiguration procedures and signalling). In addition, the IRMP augments existing management areas such as performance management, access and security management, and billing and accounting management. The IRMP interfaces to the legacy management plane for non-reconfiguration-oriented tasks, such as subscription management, software fault management, and subscriber and equipment trace management [13].

The *Data Switching Sub-Plane (DSSP)* is envisaged as an intermediary between the user plane and the MNCP. The DSSP accommodates functionality for data bearers handling when an inter-RAT handover occurs during the progress of uplink or downlink traffic exchange, including buffering and space-time traffic split. The DSSP at an Evolved Node B (E-Node B), that is a base station supporting multiple RATs, apportions and switches downlink data streams to the negotiated and selected RATs at scheduled time instances.

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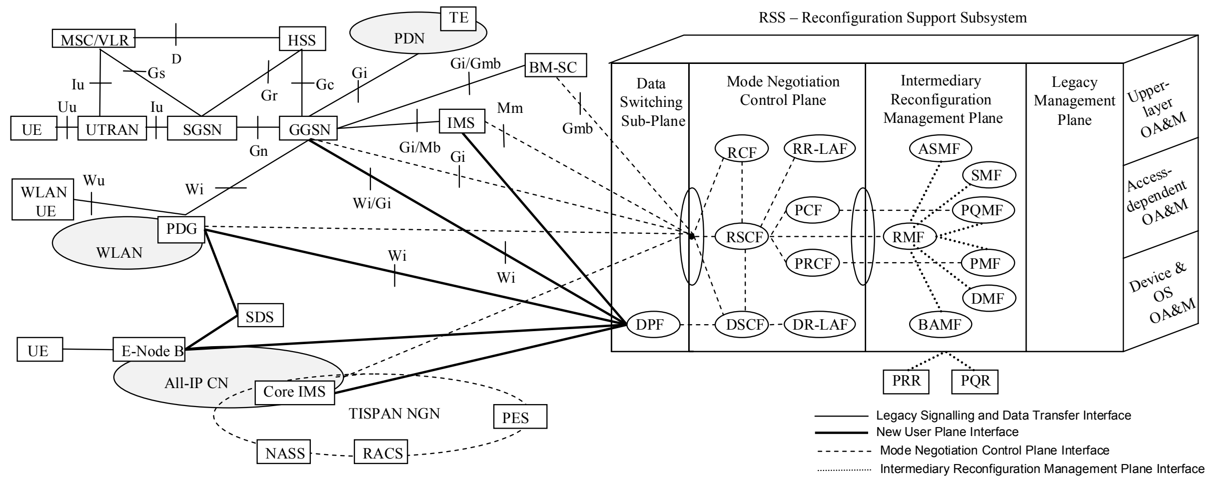

Legend

ASMF	Access and Security Management Function	**NASS**	Network Attachment Subsystem	**PRR**	Profile and Resource Registry
BAMF	Billing and Accounting Management Function	**PCF**	Policy Control Function	**RACS**	Resource and Admission Control Subsystem
CN	Core Network	**PES**	PSTN/ISDN Emulation Subsystem	**RCF**	Reconfiguration Control Function
DMF	Device Management Function	**PMF**	Performance Management Function	**RMF**	Reconfiguration Management Function
DPF	Data Processing Function	**PQMF**	Policy-based QoS Management Function	**RR-LAF**	Reconfiguration Registry Locator and Access Function
DR-LAF	Download Registry Locator and Access Function	**PQR**	Policy and QoS Registry	**RSCF**	Reconfiguration Session Control Function
DSCF	Download Session Control Function	**PRCF**	Profile and Resource Control Function	**SMF**	Software Management Function

Figure 1. The Reconfiguration Support Subsystem in a Beyond 3G mobile network architecture.

Furthermore, the DSSP allows for efficient operation of complex data transfer scenarios. For example, large-volume software downloads may pose the retrieval of software segments from more than one server, with each server being attached to more than one access network. In this scenario, mapping the DSSP logical model to a 3GPP Release 7 physical architecture yields functional entities distributed to the Gateway GPRS Support Node (GGSN), the IMS, and the WLAN Packet Data Gateway (PDG) [14].

B. Layer Management

OA&M functions are related to management of resources and parameters in each layer, thus maintaining interfaces to both the control and the management planes. For reconfigurable systems, specific layers are identified, depending on what protocol layers are adapted. The RSS incorporates three generic layers responsible for a) device and operating system reconfiguration, b) RAT switching, and c) reconfiguration via downloading and installation of *non-operational software*, i.e., upper layer (network, transport, or application) software or protocol patch. The *Device and Operating System (OS) layer* caters for the cooperation of hardware abstraction layer modules between different devices and for the coordination of reconfiguration actions by operating system controllers. The *Access-dependent layer* guarantees reliable switching between access systems. For example, switching traffic between RATs at an E-Node B necessitates support functions tailored to the specific RATs; these OA&M functions work in the background and, in contrast to the IRMP, are not associated with forthcoming user plane sessions. Finally, *Upper-layer* functions augment the TMF eTOM business and service layers [15] with user-, service-, and content-specific reconfiguration topics. Examples include customer care functions, adaptation codecs, rating and advice of charge functions.

III. Functional Specification

This section describes the functional entities of the MNCP, IRMP, and DSSP planes (Fig. 1).

A. MNCP Functional Entities

The MNCP distributes reconfiguration control responsibilities to a number of distinct functional entities, aiming at modular architectures that will support flexible business relations between administrative domains. The MNCP functional entities can be grouped to four categories:

- The terminal's contact point in the network, namely the *Reconfiguration Control Function (RCF)*;
- Session-related entities: the *Reconfiguration Session Control Function (RSCF)* and the *Download Session Control Function (DSCF)*;
- Locator and access entities: the *Reconfiguration Registry Locator and Access Function (RR-LAF)* and the *Download Registry Locator and Access Function (DR-LAF)*; and
- Policy and profile/resource control entities, namely the *Policy Control Function (PCF)*, and the *Profile and Resource Control Function (PRCF)*.

The RCF is the first contact point by the terminal in case of terminal-initiated reconfiguration. The RCF dispatches the control of individual reconfiguration sessions to the RSCF, which handles session-specific state. Accordingly, the DSCF is responsible for individual download sessions.

The RSCF exploits the RR-LAF for locating the user's Home Subscriber Server (HSS) in multi-HSS environments and for accessing the designated HSS in order to acquire subscriber-related data. Besides, the RR-LAF discovers and retrieves profile information from reconfiguration registries. In accordance with the RSCF–RR-LAF association, the DSCF interrogates the DR-LAF. The latter discovers one or more Software Download Servers (SDS) holding the target software

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modules, looks-up these modules, and delivers instructions on how to download them to the DSCF. The DSCF and DR-LAF entities extend the network-part of the OMA download architecture [12] for the case of non-operational software download.

The PCF receives reconfiguration strategies and policy rules from the IRMP *Policy-based QoS Management Function (PQMF)*, consults the RSCF on policy control issues in the case of inter-domain reconfiguration sessions, and interacts with Policy Enforcement Points (PEPs), such as the GGSN PEP. These policy rules and strategies are stored in the *Policy and QoS Registry (PQR)*.

The PRCF handles reconfiguration profile information related to users, services, terminals, and networks. Such data are delivered to the PRCF from its peer management entity in the IRMP, referred to as *Performance Management Function (PMF)*, which accesses the *Profile and Resource Registry (PRR)*. The PRCF also monitors the available network resources and keeps up-to-date state information during the progress of a reconfiguration. Besides, the PRCF receives performance measures from the PMF; these are offline reports, however, the guidelines for the measurements can be updated dynamically.

B. IRMP Functional Entities

The IRMP consists of the Reconfiguration Management Function, the Access and Security Management Function, the Software Management Function, the Policy-based QoS Management Function, the Performance Management Function, the Device Management Function, and the Billing and Accounting Management Function.

The *Reconfiguration Management Function (RMF)* triggers network-originated reconfigurations and orchestrates terminal-initiated reconfigurations. The *Access and Security Management Function (ASMF)* is responsible for a) the mutual authentication of the user / reconfigurable terminal and the RSS during the registration procedure, b) the verification of authorization to download, and c) the determination of security mechanisms (e.g., agreement on security keys) prior to download transfer. The *Software Management Function (SMF)* triggers reconfiguration actions upon the availability of new software or protocol versions. The PQMF is responsible for background configuration of network elements with QoS policies (QoS data path state) according to scheduled download actions and based on dynamic service level specifications. The PMF schedules and collects performance measures such as attempted, successful, and failed reconfigurations, as well as usage data, reconfiguration session accounting information, and packet-flow-based accounting information. The *Device Management Function (DMF)* designates the available protocol stack configuration procedures and options to the terminal. In addition, it is responsible for reporting the device capability options to the RMF and for offering open standardized interfaces for remote equipment management. Finally, the *Billing and Accounting Management Function (BAMF)* aggregates charging records generated from network elements such as the GGSN/SGSN, the IMS, and WLAN gateways due to reconfiguration signalling and download traffic. The BAMF processes these records and apportions the reconfiguration-induced revenues to the involved business actors. Finally, the BAMF generates advice of charge notifications to end-users triggered by the corresponding layer management functions.

C. DSSP Functional Entities

The DSSP *Data Processing Function (DPF)* mediates for the provision of resources (buffer space, scheduling disciplines) to be controlled by the PRCF. In case of inter-system handover, the DSCF commands the DPF to split and switch data streams to multiple RATs.

IV. Staged Reconfiguration Process

Fig. 2 identifies five generic terminal reconfiguration stages, inline with radio software download requirements set by the SDR Forum [4].

A. Reconfiguration Registration

This stage provides the terminal with the capability to attach to an RSS and - optionally - to be informed about the current *Network Reconfiguration Profile (NRP)*. Accordingly, this stage allows the RSS to record the presence of a terminal, to retrieve subscriber-related data from the user's HSS, and to be informed about the current *Terminal Reconfiguration Profile (TRP)*. At this stage, the TRP includes the initial option set for the User Equipment (UE), i.e., for the specific subscriber and mobile equipment. Similarly, the NRP expresses the access networks and modes currently available to the UE.

The reconfiguration registration stage is governed by the RCF. In addition, the RR-LAF locates the user’s HSS, accesses the discovered HSS (via a Parlay gateway), and fetches subscriber-related data. Finally, the RR-LAF retrieves the NRP instance from the PRR. Security steps (e.g., mutual authentication) are beyond the scope of this paper.

B. Reconfiguration Session Establishment

The Terminal Reconfiguration Control Function (T-RCF) contacts the RSS-RCF upon detection of a new RAT. RAT discovery can be either terminal-initiated or based on software advertisements [16]. The RSS-RCF dispatches the request to the RSCF, which logs a new reconfiguration session. Then, the RSCF requests the protocol configuration profile from the T-RCF, i.e., the list of feasible protocol stack stratifications. It is worth noting that only protocol configuration information is requested, as frequent software upgrades expected in next-generation networks will yield a wide range of terminal classes. Therefore, the detailed terminal capabilities are not transferred over-the-air in this step, aiming to save wireless resources. Instead, such detailed information will be exchanged provided the terminal approves the reconfiguration.

The T-RCF evaluates local policy rules, compiles the protocol configuration profile, and delivers it to the RSCF. At this point, the RSCF requests the approval of the reconfirmation decision by the terminal. In order to validate the response, the T-RCF juxtaposes the command with local reconfiguration strategies. In the case of positive

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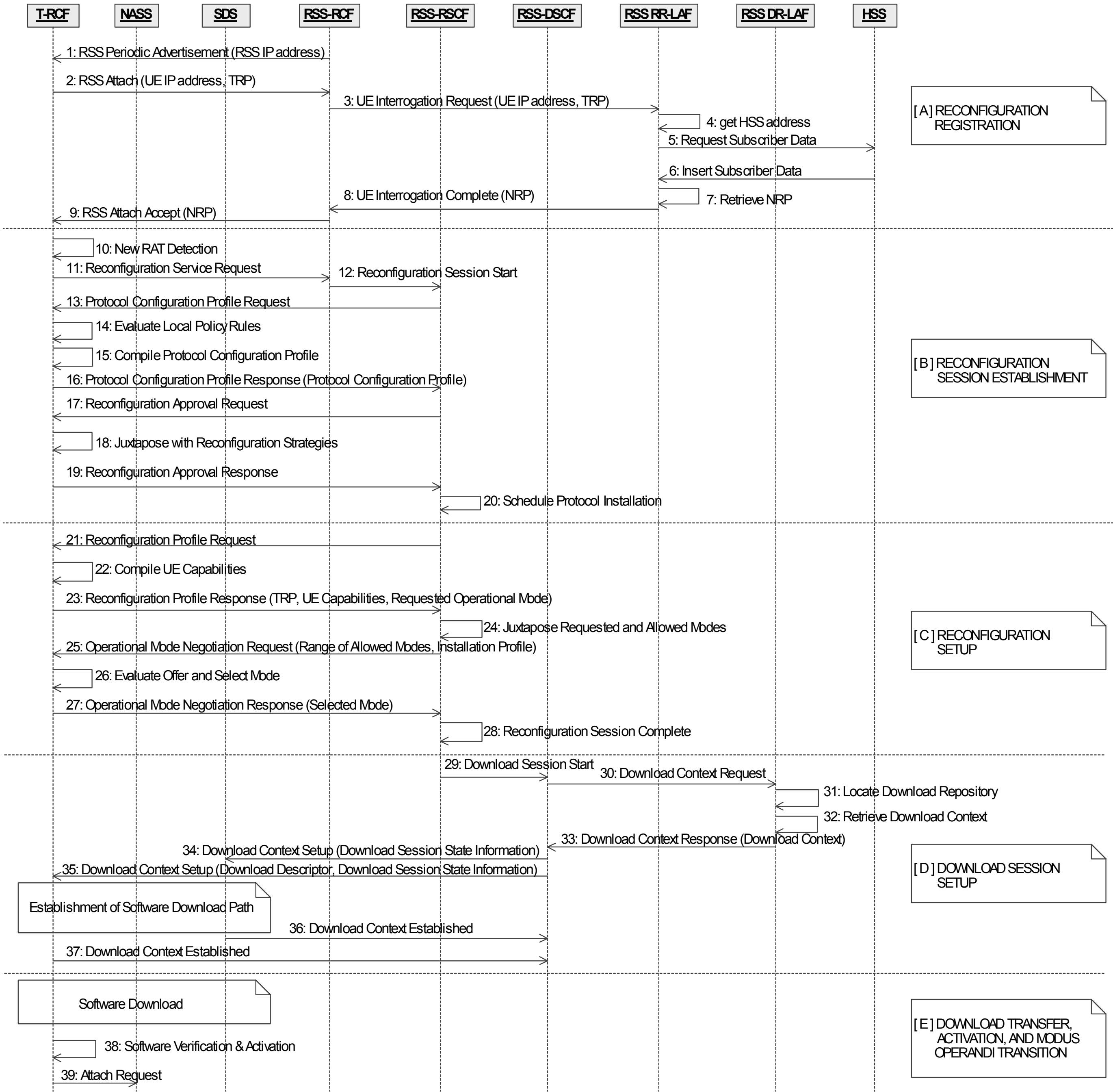

Figure 2. Signalling exchange for terminal reconfiguration via over-the-air software download.

acknowledgement, the RSCF schedules the protocol installation.

C. Reconfiguration Setup

This stage engages a number of loops in which the terminal and the network exchange their capabilities in order to negotiate the terminal and the network mode of operation (Fig. 2 illustrates one loop). The decision depends on quality of service requirements posed by the selected modes to the network elements that will be on the path of forthcoming data sessions. Each round of the offer/answer model consists of the following steps: firstly, the RSS acquires the up-to-date instance of the TRP, the current UE capabilities, and the requested protocol mode operation. Freshness of the TRP and capability information is imperative due to frequent reconfigurations. Next, the RSS juxtaposes the requested mode with the allowed ones, and informs the terminal about the range of offered modes and the associated protocol installation profile. The terminal processes the offer and selects the optimal mode.

When the T-RCF reports the decision to the RSCF, the latter closes the record related to this reconfiguration session and hands over the control to the DSCF.

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D. Download Session Setup

During this stage, the DR-LAF locates the download repositories, and retrieves and delivers the download context to the DSCF. In addition, the DSCF triggers the download context setup between the T-RCF and the SDS that aims to assist in resource reservation along the software download path.

E. Download Transfer, Activation, and Modus Operandi Transition

The remaining steps of the reconfiguration process are rather straightforward: the protocols comprising the new RAT are downloaded, the software is verified and activated, and the terminal attempts to attach to a new access network via communication with the NGN Network Attachment Subsystem (NASS) [10]. Finally, the T-RCF switches to the new RAT and transits to the selected operational mode.

V. Conclusions

This paper identified the key components of Next-Generation Mobile Networks, as multi-radio systems coupled with evolved core network architectures, exploiting terminal reconfiguration in heterogeneous service environments. Inline with IMS philosophy, a unified framework was proposed, introducing distinct user, control, and management planes for reconfiguration-specific tasks, as well as OA&M functions.

Introducing additional intelligence into new planes allows for independent evolution paths and refinements to the legacy control and management planes. The principle of mapping additional functionality to new planes has been well-received in the telecom and IT communities, with 3GPP separating the UTRAN transport network control plane from the legacy control and user planes [17] and IETF working on forwarding and control element separation [18]. The alternative of integrating new functions to existing planes dictates continuous updates to systems under operation whenever new reconfiguration features are developed.

From deployment perspective, the RSS comprises a stand-alone network element that aims to functionally support the reconfiguration process in a way transparent to future network infrastructures. In a Beyond 3G context, the RSS resides in the core network of a 3GPP system or in a trusted third party domain, and interfaces to the GGSN/SGSN, the IMS, the Broadcast/Multicast Service Centre (BM-SC) for mass upgrades, and WLAN/WiMAX access systems. To address scalability, each RSS is responsible for offering reconfiguration services within a designated area. Although decentralisation is not a panacea, the functional entities that comprise the RSS can be distributed to network elements over network and service provider domains. The RSS control and management plane model per se (i.e., the MNCP and the IRMP) can also be applied to terminal equipment. In addition, the RSS framework can be generalised to fixed networks.

The subsystem-oriented rationale allows next-generation architectures to be adjusted with no or limited impact on other subsystems. Besides, it enables the addition of other subsystems to cover future demands. This approach offers the gradual introduction of reconfiguration as plug-and-play feature; whether RSS interfaces are implemented or not shall have limited impact on other entities of a PLMN, in the same way the optional Gs interface can be transparently deployed [19]. Hence, RSS can be rolled-out gracefully when SDR/CR equipment is installed, with no impact on the operation of already deployed 3G systems; specifically, new Network Operation Modes (NOMs) can be proposed (NOM IV, V, etc.) for optional interfacing RSS to the GGSN/SGSN, the IMS, the BM-SC, and WLAN gateways. Furthermore, the described RSS procedures can be seamlessly supported in Iu mode, in the same fashion CAMEL procedures are optionally triggered during, for example, location management procedures [19].

Next steps include analysis of the available protocol pool for mode negotiation and context transfer, encoding of reconfiguration profiles, and interface specification, aiming at a proof-of-concept RSS prototype.

Acknowledgment

This work has been performed in the framework of the EU funded project E²R II. The authors would like to acknowledge the contributions of their colleagues from E²R II consortium.

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