End-to-End Architecture for Adaptive Communication Systems

Z. Boufidis, N. Alonistioti, and M. Stamatelatos
University of Athens, Greece
boufidis@di.uoa.gr

J. Vogler
Panasonic R&D Center Germany GmbH

U. Lücking
Nokia Research Center, Germany

C. Kloeck
University of Karlsruhe, Germany

D. Grandblaise and D. Bourse
Motorola Labs, France

Abstract—**Reconfigurability is considered the collection of software and cognitive radio technologies that aim to differentiate user perception in volatile radio conditions while optimizing the use of network resources. The realization of equipment reconfiguration through software download and the efficient utilisation of spectrum require coordinated distribution of functionality among the user, control, and management planes. This contribution presents the end-to-end architecture of future adaptive communication systems based on the Reconfiguration Management Plane model, which includes intelligence for policy-based context-aware decision making, negotiation control, software download, and dynamic spectrum management. The paper presents the RMP functional model, describes the dependencies and associations of the constituent context management module, and delineates the end-to-end quality of service negotiation information flow when introducing dynamic spectrum access in user-to-user communication scenarios.**

Index Terms—**autonomic communications, context management, dynamic spectrum access, reconfigurability, software download, system architecture**

I. Introduction

Next-generation mobile networks are expected to integrate emerging wireless personal, metropolitan, and regional access networks into already developed cellular/Wi-Fi air interfaces. 3GPP has started to work on the long-term evolution of the UTRAN, setting high-level requirements such as reduced cost per bit, increased service provisioning, flexible use of the frequency bands, and lower power consumption at the terminal equipment. In addition, advances in the core network pave the way for the full exploitation of IP transport and mobility on top of heterogeneous wireless and wireline networks. The major research challenges for such adaptive communication systems are intersystem handover, discovery and selection of new access systems based on operator policies, ambient knowledge, and user preferences, maintenance of the negotiated end-to-end quality of service (QoS), and integration of policy and charging control. On the other hand, software and cognitive radio has been the subject of intensive research in the telecom community, aiming to upgrade the capabilities of reconfigurable equipment according to user requirements and network conditions, and to fully exploit the available spectrum resources temporally and spatially.

This contribution proposes an integrated end-to-end architecture for such adaptive communication systems developed in the context of the EU FP6 Integrated Project IST-E²R (End-to-End Reconfigurability) [1]. The architecture consists of multi-access radios coupled with evolved core networks, accommodating software and cognitive radio facilities. This manuscript provides a synthesis of the works in [2] [3] [4].

The paper is organized as follows: The concept of a Reconfiguration Management Plane (RMP) that provides a logical means of structuring work on reconfigurability is highlighted in Section II. The following section provides the main design axes pertaining to the end-to-end functional architectural. A UML model describing the associations and dependencies of the RMP context management module is elaborated in Section IV, whereas the baseline information flow for bridging dynamic spectrum access and end-to-end quality of service can be found in Section V. Conclusions and next steps are delineated in Section VI.

II. The Reconfiguration Management Plane

Reconfiguration is a set of policy-driven tasks for modifying the operation or behaviour of systems, network nodes and elements, as well as capabilities of functional elements. This paper envisages reconfigurable next-generation networks as the class of multi-modal radio systems coupled with evolved core network architectures, whereas integrating software and cognitive radio capabilities. In the short term, end user devices and base stations will be reconfigured, although it is expected that in the long-term interior network elements will have to be dynamically upgraded in order to provide a homogeneous reconfiguration workflow along the end-to-end data path. The end-to-end perspective dictates that, in certain cases, user and control plane interactions occur from source to destination in order to adapt the system operation and modify the operational mode of equipment and software modules. Such interactions should be coordinated by a cohesive support plane aiming at diverse service offering. The RMP comprises a functional plane for the management of reconfiguration, that is, it encapsulates control, management, and Operations, Administration, and Maintenance (OA&M) functions that govern the interactions between the involved entities and orchestrate the decision making and enforcement of mechanisms supporting reconfiguration in a dynamic fashion.

The concept of a new management plane in support of control plane functions has been a well-established approach in the telecom community. This rationale has been initially sketched and transferred in the reconfigurability thematic in [5][6]. The authors in [5] propose a software-map to control the description of the software layout of the reconfigurable radio part of mobile terminals and argue that this functionality could be supported in the form of a reconfiguration support plane. Ref. [6] also proposes a reconfiguration management plane focusing on value-added service provision to reconfigurable terminals. In contrast to these efforts, the authors in [2] propose a framework for reconfiguration operations and signalling with clear separation between control, management, and OA&M functions, stretching from reconfigurable nodes to the support infrastructure. This functional plane is not restricted to software configuration profiles and service provision; on the contrary, the RMP addresses technical challenges such as software upgrades through over-the-air software download, dynamic network selection and adaptation, and flexible spectrum management. In accordance with the 3GPP Integration Reference Point (IRP) specification stages [7], the RMP comprises a network-agnostic protocol-independent model for specifying the triggering, negotiation, decision making, and coordination of reconfiguration in order to achieve physical-implementation-independent procedures and signalling. Ref. [2] further analyzes the design and deployment issues pertaining to the adoption of a reconfiguration management plane in a Beyond 3G network.

III. End-to-End System Architecture

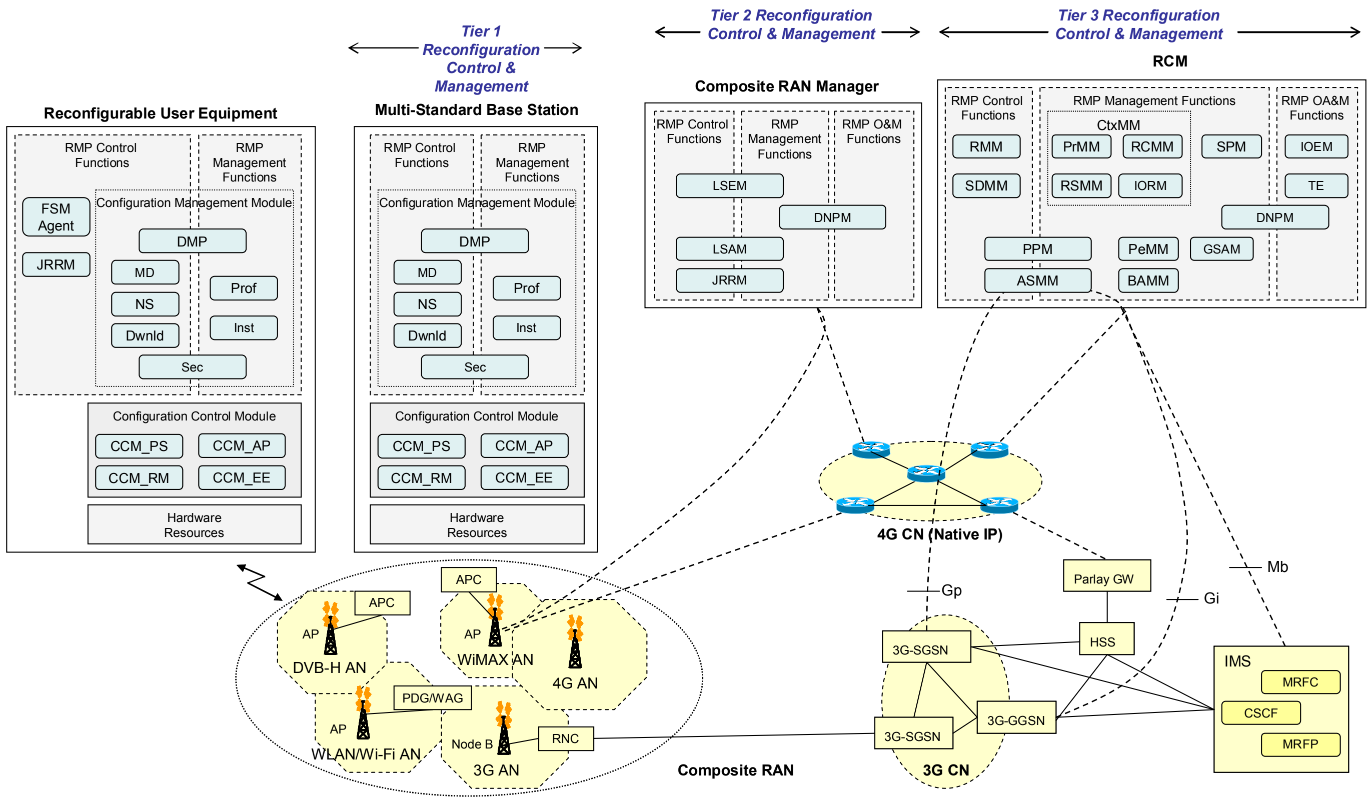
Fig. 1 sketches the mapping of the RMP logical model to a Beyond 3G physical configuration. The enhanced RMP model consists of control, management, and OA&M functions that cater for reconfiguration-induced tasks such as reconfiguration session control and negotiation of end-to-end QoS, policy-based decision making based on contextual information, control of software download steps [2], as well as for joint radio resource management (JRRM), dynamic network planning and management (DNPM) [8], and flexible spectrum management (FSM) [3]. Legacy management areas are enriched in order to capture reconfiguration-oriented aspects, such as profile 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 functions, which handle OA&M tasks per protocol layer.

Fig. 1 shows a three-tier control/management architecture for composite reconfigurable networks. In this architecture, composite Radio Access Networks (RANs) support a multitude of Radio Access Technologies (RATs), with the optimal radio invoked on-demand. The figure shows composite RAN environments coupled with scenarios of evolved core network architectures. The reconfigurable equipment (i.e., the end-user devices and tier 1, that is, the Multi-Standard Base Station, MSBS) accommodate RMP functionality in the form of the so-called Configuration Management Modules (CMM), which are responsible for the orchestration of the reconfiguration procedures, and the Configuration Control Modules (CCM), which translate commands and capabilities from an underlying-technology-independent way to technology-specific commands and capabilities [4]. Tier 2 consists of the Composite RAN Manager (CRM), which manages a composite RAN, thus being responsible for functions such as JRRM, DNPM, and FSM [3]. Finally, the anchor ReConfiguration Manager (RCM) comprises the third tier and lies beyond the network access server (e.g., the GGSN), in the core network domain or in a trusted third party [2]. Details on the functional entities depicted in Fig. 1 can be found in [2][3][4].

IV. Context Management

Contextual information is the main input to reconfiguration actions in a reconfigurable element or system. Reconfiguration can be considered as dynamic adaptation of the system to context changes during the system's lifecycle. Context management includes information representation, information model composition from raw data, as well as information update, retrieval, exchange, and transformation. In reconfigurable environments, contextual information includes profile information, resource attributes, and the so-called reconfigurability classmark. Profile information includes information describing the various entities of the system ranging from equipment capabilities to user preferences. Fig. 2 illustrates a UML model for context management depicting the baseline concepts and the corresponding interactions. The basic contextual information is composed by the ProfileData and the GenericResource. The ModemConnectivityLayerProfile, the SoftwareLayerProfile, and the UpperLayerProfile represent special profile cases and reflect a layered profiling approach. Specifically, the ModemConnectivityProfile is composed of a number of ProfileComponent components providing device configuration capabilities. Alike, such a dynamic composition for the SoftwareLayerProfile case describes the various software features existing within an autonomously reconfigurable device, whereas the UpperLayerProfile consists of user-related information, charging capabilities, and service provision and reconfiguration preferences.

From a different perspective, specific sets of the aforementioned ProfileComponents may compose user,



3G	Third Generation	GSAM	Global Spectrum Allocation Manager	RAN	Radio Access Network
4G	Fourth Generation	GW	Gateway	RAT	Radio Access Technology
AN	Access Network	HSS	Home Subscriber Server	RCM	ReConfiguration Manager
AP	Access Point	IMS	IP Multimedia Subsystem	RCMM	Reconfigurability ClassMarking Module
AP (CCM_AP)	CCM Application Layer	Inst	Installation	REMM	Reconfigurable Equipment Management Module
APC	Access Point Controller	IORM	Inter-Operator Resource Manager	PM	Reconfigurable Modem
ASMM	Access and Security Management Module	IOEM	Inter-Operator Economic Manager	RMM	Reconfiguration Management Module
BAMM	Billing and Accounting Management Module	JRRM	Joint Radio Resource Management	RMP	Reconfiguration Management Plane
CCM	Configuration Control Module	LSAM	Local Spectrum Allocation Manager	RNC	Radio Network Controller
CMM	Configuration Management Module	LSEM	Local Spectrum Economic Manager	RSMM	ReSource Management Module
CN	Core Network	MD	Monitoring and Discovery	SDMM	Software Download Management Module
CSCF	Call-Session Control Function	MRFC	Multimedia Resource Function Controller	Sec	Security
CtxMM	Context Management Module	MRFP	Multimedia Resource Function Processor	SGSN	Serving GPRS Support Node
DMP	Decision Making and Policy enforcement	NS	Negotiation and Selection	SPM	Service Provision Module
DNPM	Dynamic Network Planning and Management	O&M	Operations, Administration, and Maintenance	SS	Strategy Scheduler
Dwnld	Download	PDG	Packet Data Gateway	TE	Traffic Estimator
DVB-H	Digital Video Broadcast – Home	PeMM	Performance Management Module	WAG	WLAN Access Gateway
EE	Execution Environment	PPM	Policy Provision Module	Wi-Fi	Wireless Fidelity
FSM	Flexible Spectrum Management	PrMM	Profile Management Module	WiMAX	Wireless Interoperability for Microwave Access
GGSN	Gateway GPRS Support Node	PS	Protocol Stack	WLAN	Wireless Local Area Network
GPRS	General Packet Radio Service	Prof	Profile		

Figure 1: End-to-end architecture for reconfigurable mobile systems and networks Beyond 3G

software, and device profile instances. This is depicted in Fig. 2, where the SystemContext represents capabilities (profile information) that are exchanged and negotiated between autonomic reconfigurable devices. The DeviceProfile captures static profile information in terms of detailed capabilities as well as device configuration as pointed out by the corresponding attributes. Further, the ReconfigurabilityClassmarking module provides the corresponding device classmarking based on profile information. Such classmark is envisaged as the corresponding signature of the device profile reflecting the reconfiguration-related capabilities of a given device. A list of attributes has been included enabling ReconfigurabilityClassmarking to act as a classifier within the device profile information. In this sense, the classmarking is considered as inferred knowledge for a specific device. Both ProfileManagement and ReconfigurabilityClassmarking modules feed the Autonomic DMP module for decision making purposes.

System resources form another type of reconfigurability contextual information. A GenericResource may include a new dynamically installed scheduling discipline, bandwidth, radio bearer power, and spectrum resources. The corresponding resource manager includes spectrum economic and allocation managers. Finally, performance management defines the PerfomanceMeasures to be executed by the ResourceManagement module.

V. Dynamic Spectrum Access and End-to-End QoS

SystemContext comprises the contextual information of nearby entities that can be exploited in order to optimise the operation of reconfiguration actions. Spectrum resources (frequency segments, power levels, and codes) is a kind of

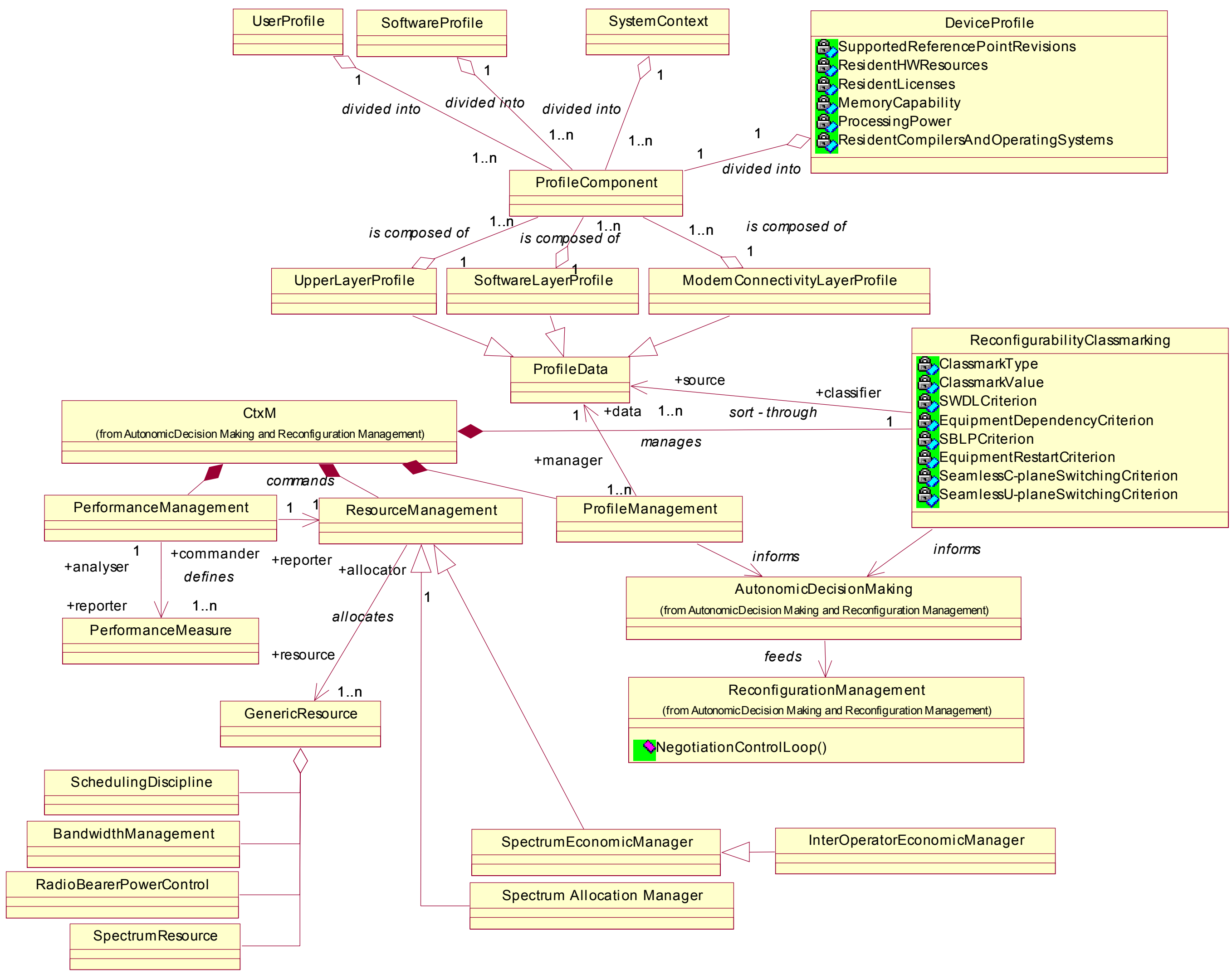


Figure 2. UML model for context management

resource that can be exploited in order to modify the QoS offered to user sessions. The major building blocks involved in flexible spectrum management are the DNPM module, and the global/local spectrum economic and allocation managers.

Dynamic network planning and management (DNPM) spans both management plane and layer management (Fig. 1). The DNPM management plane module undertakes the so-called *DNPM management phase*, which aims at dynamic proactive adaptation of radio elements and at optimal parameter settings for supporting oncoming user plane sessions. DNPM management plane scenarios include remote electric tilting, reallocation of spectrum layers to base stations, and reconfiguration of multi-standard base stations. DNPM functions that belong to the so-called *DNPM initial planning phase* are decoupled from oncoming user-plane sessions; hence, they are logically modelled as layer management (OA&M) functions.

The spectrum economic and allocation management modules assign generic spectrum resources to different RATs and calculate optimal guard bands between adjacent RATs. The Global Spectrum Allocation Manager (GSAM) computes the best opportunity for spectrum division to operator's RATs. The Local Spectrum Allocation Manager (LSAM) assigns traded/negotiated spectrum resources to individual users while guaranteeing inter-system and intra-system (co-channel) interferences are within acceptance limits. In addition, the Local Spectrum Economic Manager (LSEM) receives spectrum bids from users and decides the amount and price of spectrum resources for each user.

Flexible spectrum management can be achieved through the usage of auctioning between the terminals and the access point (e.g., of a WLAN-like system) to allocate radio resource goods. With that mechanism, the terminal bids for an amount of "money" proportionally to its needs, that is, to its required QoS for a given period of time. In case of end-to-end connection (i.e. between two terminals located into two different cells where auctioning is applied), this

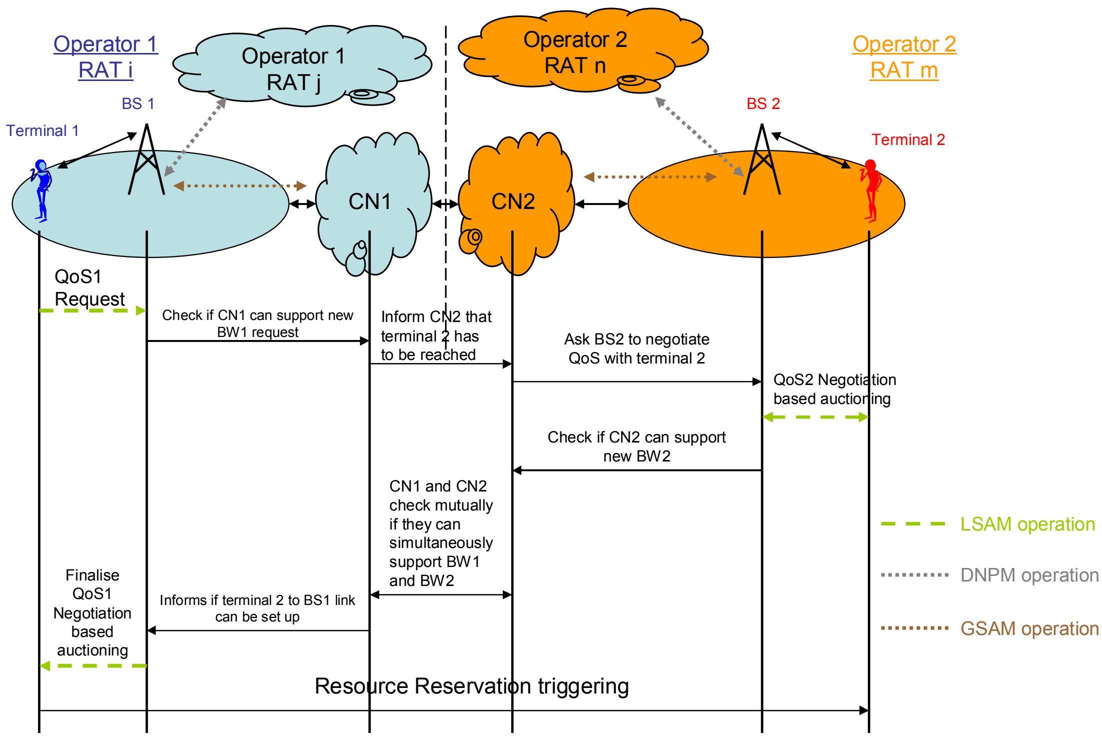


Figure 3. Binding dynamic spectrum access and end-to-end QoS negotiation

auctioning-based radio resources goods allocation raises also some key issues from the network side. Indeed, since auctioning can occur very shortly for very large bandwidth requests over the air, the network is supposed to adapt dynamically and very shortly to (i) identify if the link between the two terminals can be established, and (ii) reserve the needed bandwidth at the core network (CN) to establish this link. This is all the more challenging in case the two terminals are not operating the same RAT (i.e., belong to two different core networks). Fig. 3 illustrates how a connection could be set up between the two terminals taking into account the CN elements. Relationship with functional blocks of the system architecture is also included.

VI. Conclusions

Envisaging an integrated architectural approach for end-to-end reconfigurable mobile systems and networks, this paper has adopted a unified rationale aiming to integrate policy-based context management and dynamic spectrum access capabilities in the form of the Reconfiguration Management Plane. E^{2}R II project aims to foster the RMP model accommodating the emerging autonomic communications paradigm [9], whereas taking into account recent trends in the long-term evolution of mobile communication systems and networks [10].

Acknowledgment

This work has been performed in the framework of the EU funded projects E^{2}R and E^{2}R II. The authors would like to acknowledge the contributions of their colleagues from E^{2}R and E^{2}R II consortia.

References

[1] EU IST Project E^{2}R II (End-to-End Reconfigurability – Phase 2), http://www.e2r.motlabs.com/

[2] Z. Boufidis, R. Falk, N. Alonistioti, E. Mohyeldin, N. Olaziregi, and B. Souville, “Network Support Modeling, Architecture, and Security Considerations for Composite Reconfigurable Environments”, IEEE Wireless Commun., vol. 13, no. 3, June 2006.

[3] C. Kloeck, *et al.*, “Functional Architecture of Reconfigurable Systems”, WWRF#14, San Diego, California, July 2005.

[4] J. Vogler, *et al.*, “Equipment Management and Control Architecture”, July 2005, E^{2}R White paper, available at http://e2r.motlabs.com/whitepapers/

[5] K. Moessner, S. Gultchev, and R. Tafazolli, “Managing Reconfiguration in Software Communication Systems”, 6th International Symposium on Communication Theory and Applications, Ambleside, United Kingdom, July 2001.

[6] M. Dillinger, K. Madami, and N. Alonistioti, Eds., *Software Defined Radio: Architectures, Systems and Functions*, Wiley, 2003.

[7] 3GPP TS 32.150: “Telecommunication management; Integration Reference Point (IRP) Concept and definitions (Release 6)”.

[8] P. Demestichas, *et al.*, “Radio Resource Management and Network Planning in a Reconfigurability Context”, Proc. 13th IST Mobile and Wireless Commun. Summit, Lyon, June 2004.

[9] J. Strassner, “Autonomic networking – theory and practice”, Proc. 9th IFIP/IEEE International Symposium on Network Management, Nice, France, May 2005.

[10] 3GPP TR 23.882: “3GPP System Architecture Evolution: Report on Technical Options and Conclusions (Release 7)”, May 2006.