Functional Architecture of End-to-End Reconfigurable Systems

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Abstract — Adaptive networks are envisaged to play a significant part in the future, where the time and space variations in the traffic pattern will necessitate the ability to continuously amend the Radio Access Technologies' (RATs') operating parameters. Reconfiguration of communications systems is a facilitator towards this convergence and enables the dynamic adaptation and optimization of the access characteristics. However, such far ranging optimization concept involves many different mechanisms and work areas. Each of these areas provides an answer to a different optimization problem; Dynamic Network Planning and Management (DNPM) provides a load and demand driven optimization of the radio planning of multiple different networks within a given area. Advanced Spectrum Management (ASM) enables short term use of spectrum for services with higher demand. Finally Joint Radio Resource Management (JRRM) coordinates different access schemes and facilitates a more centralized approach to allocation of radio resource. Each of the schemes optimizes spectrum and radio resource usage on a different time scale. ARRM deals with the rather short term allocation, ASM with more medium term spectrum assignments while DNPM assumes time scales up to the range of weeks or months. Consequently, there is need of combining all working areas in the form of a Functional Architecture (FA), where each module represents a concept, aiming at forming part of the global end-to-end reconfigurability architecture. This paper includes a detailed analysis of the Reconfigurability FA, along with a description of the functionality of each of the modules included therein.

Keywords: *End-to-end Reconfigurability, Functional Architecture (FA).*

I. INTRODUCTION

The world of telecommunications is characterized by the coexistence of a multitude of diverse Radio Access Technology (RAT) standards. The most commonly used include traditional cellular networks, wireless shorter-range networks and broadcasting systems. Furthermore, the evolution of wireless communications can be summarized in the migration of today's technologies towards the systems beyond the third generation (B3G), aiming at the provision of highly sophisticated services, transmitted at higher data rates,

in a cost effective manner. B3G is expected to be based on IP technology yielding into a common, agile and seamless all - IP [1] architecture design, supporting scalability and mobility. In such context, the possibility of diverse RATs to be optimally combined and coordinated under a global infrastructure called "*B3G wireless access infrastructure*" stands as a basic prerequisite for the consolidation of B3G systems [2].

This convergence is facilitated by the interworking of previously competent - networks [3],[4],[5],[6], and (perhaps most importantly) by the evolution of adaptive networks [7]. Networks' interworking imposes cooperation among Network Providers (NPs), so as to jointly handle extreme traffic situations [8],[9], by splitting traffic among their RATs. For this purpose, the whole set of RATs should be deployed in both network segments and terminals a priori. Adaptive networks, acting complementary to Software Defined Radio (SDR) [10], are able to dynamically adapt their behavior to various conditions (e.g., hot-spot situations, traffic demand alterations, etc.) at different time zones and spatial regions, by exploiting deployments with much fewer pre-installed components. In other words, adaptive networks allow their segments to dynamically select and configure the set of the most appropriate RATs, in order to better handle service area regions or time variant requirements [11],[12].

The introduction of such intelligent systems has two primary objectives: (1) Highly reliable communication whenever and wherever needed, and (2) efficient utilization of the radio spectrum. The activities in E²R project [7] aim at translating the vision of adaptive systems into reality. This will be done by investigating and introducing concepts in Advanced Spectrum Management (ASM), Joint Radio Resource Management (JRRM), and Dynamic Network Planning and Management (DNPM). Dynamic spectrum access and on-the-fly availability of new RATs shall trigger control and management interactions from source to destination in order to adapt the system (e.g., network elements on the end-to-end path), the equipment (e.g., function relocation), the application, the service or the

content. Hence, the end-to-end notion dictates the proposal of *coordinated* management and control functions that govern the interactions between the involved entities, and for governing the decision-making and enforcement of mechanisms supporting reconfiguration in a dynamic fashion.

Furthermore, this paper constitutes a first step towards a combination of the aforementioned working areas, in the form of a functional architecture, each module of which represents a working area that is an indispensable part of adaptive systems. For this purpose, the next section contains a brief overview of the architecture, while the full version of the paper will also analyze each of the modules in detail, in section 3. Concluding remarks are drawn in section 4.

II. FUNCTIONAL ARCHITECTURE OVERVIEW

This section contains a high level description of the functional components that comprise the architecture of future, adaptive (reconfigurable) systems.

The provision of end-to-end reconfiguration services and reconfiguration management in Composite RAN environments, coupled with scenarios of evolved core network architectures [13], should be accommodated within control and management architectures. From a high-level perspective, the architecture consists of ReConfiguration Manager (RCM), RAN Reconfiguration Support Function (R-RSF) and the Composite RAN Manager (CRM). The R-RSF and CRM manage a single or a Composite RAN, respectively, thus being responsible for functions such as aforementioned ASM, DNPM and JRRM.

Figure 1: Functional Blocks Overview

The ASM will optimize the spectrum allocation adaptively. This includes the optimization of guard bands between the Radio Access Technologies (RATs). The JRRM

should handle the optimization of traffic through the available RATs. One of the main concerns of JRRM is the vertical handover between RATs. The DNPM algorithms deal with the dynamic radio cell behavior through power allocation and antenna techniques. The ASM, JRRM and DNPM will take the evolution of mobile communication systems one step further towards cognitive radio.

The functionalities of DNPM, ASM and JRRM are closely interlocked and coupled (see Figure 1). Nevertheless the interworking of these three concepts can be considered as three interlocked loops. Each loop reacts based on the output parameters of the adjacent ones. The more inner a loop is located, the faster is their reaction time. Therefore the entities of the middle and inner-loop should be locally decentralized in order to combat delay through the route to a central entity. The function of the outer-loop can be executed in a central entity at a central place, e.g. for GSM in the core network.

III. DETAILED DESCRIPTION OF BLOCKS

This section contains a more detailed description of all of the functional architecture blocks outlined above.

A. Meta Operator

The Meta Operator will allocate the spectrum to operators and will not mandatory possess spectrum, that is, it can only trade with spectrum. This occurs in the outer loop.

B. Inter Operator Economic Management (IOEM)

IOEM aims at providing the economical functionalities for dynamic spectrum allocation. That is, the pricing and billing mechanism will be provided especially for spectrum pooling and sharing. The negotiation between operators will happen in long-term and therefore can be executed in a centralized manner. Long-term means days or even hours, so that DNPM can trigger negotiation with other operators concerning sport event or dynamic hot spots. This occurs in the outer loop.

C. Inter Operator Resource Management (IORM)

After trading the spectrum by IOEMs and Meta operator, the IORM aims at optimizing the spectrum usage efficiency subject to the arrangement to the spectrum got. Based on the database from the Meta operator or the current spectrum usage from the renting operators, the optimal location of the spectrum and the borrowed spectrum and the relevant guard band will be calculated. Furthermore, joint operation between implementation parameters, e.g., antenna tilting angle will be executed. The functionalities will react in long-term. This occurs in the outer loop.

D. Dynamic Network Planning and Management (DNPM)/Global Spectrum Allocation Manager (GSAM)

DNPM is a framework dealing with planning and managing a reconfigurable network. It consists of a planning phase and a management phase. During the initial planning phase, feasibility of setting radio interfaces; location of base

stations; antenna patterns; coupling structure among sub-networks; policy of *Joint Radio Resource Management* (JRRM); and statistic values of required spectrum in different scenarios with available *Radio Access Technologies* (RATs) are developed. In the management phase, radio network elements are subject to be reconfigured. Reconfiguration is triggered by the management entities, e.g., the network element manager, so that optimal adjustment of a radio network targeting optimal parameter settings can be carried out. Typical scenarios of DNPM are the *Remote Electric Tilting* (RET), Re-allocation of the Spectrum layers to the base station, reconfigurable *Multi Standard Base Station* (MSBS).

Since the dynamic release/reallocate the spectrum named as GSAM (*Global Spectrum Allocation Manager*) in the base station is one important function executed by the O&M subsystem, which changes the operating spectrum of their *Radio Access Technologies* (RATs), we define this function in the same level of the DNPM. In most cases, this function works faster than antenna tilting and network element reconfiguration in the scenario of MSBS¹.

The interrelationship to other functional modules is depicted in Figure 2, where the DNPM/GSAM module interworks with the traffic estimator, the ARRM modules in the radio subsystem, the Local Spectrum Economic Manager, the Local Spectrum Allocation Manager, the Network Element, e.g., Base Station, RNC, etc.

Figure 2: Inter-relationship of DNPM/GSAM with other functional blocks

E. Local Spectrum Economic Management (LSEM)

In line with the space and time dependent spectrum

¹ In fact, the optimal solution for a hybrid network reconfiguration mechanism called *Hybrid Radio Element Management and Resource Management* (HRERM) is still under research. Therefore, the time scale comparison between those use cases is still left open.

allocation in the higher logical layers (IOL, OL), the spectrum allocation and the price of spectrum usage will also be space and time dependent, therefore the LSEMs will be distributed and a LSEM will be responsible for one base station. The task of LSEM is to provide all the functionalities to give the users spectrum allocation credits after a certain trading mechanism with respect to efficiently trade the spectrum and to optimize the economical gain of the operator.

Based on Cognitive Radio, the user's terminal is no longer a "stupid" entity, moreover it is able to learn about its environment and act according the experience. Consequently, the terminal is going to estimate its need for spectrum, calculates an evaluation of the spectrum and expresses individually the need of spectrum by a bidding vector. This new ability inherently in Cognitive Radio allows other trading opportunities, e.g., negotiation and auctioning. Taking into account the channel as the bottleneck of a wireless communications system, the best choice of a trading mechanism allowing Cognitive Radios to apply its main characteristics is a sealed-bid auction.

The LSEM including the above mentioned Cognitive Radio concept reacts in the middle-loop and short-term.

F. Local Spectrum Allocation Manager (LSAM)

Given the outputs of the auctioning between spectrum users, the LSAM is in charge of finding the appropriate frequency assignment of the spectrum between users to ensure the co-channel interference intra and inter systems is well managed. This auctioning can be seen as an extension of the MAC of established systems while being also backward compatible to the established system (i.e. it is also applicable in the context of e.g. classical 2G/3G cellular systems where the management and control of the radio resources is always carried out from the network side).

Figure 3: Internal LSAM functional block description

G. ASM Agent

The ASM Agent aims at calculating the bids for GRECs subject to budget constraint and to maximizing users' satisfaction which is expressed in terms of QoS.

The functionalities are based on the cognitive radio concepts and will complete the LSEM functionalities on the operator's side. (See argumentation for LSEM).

The bids will be calculated based on QoS- buffer size, QoS – buffer size change, number of critical data which should be urgently sent, budget constraint, individual Importance of Service (IoS), reserved price and the history of auction the user has already participated.

H. Reconfiguration Agent

The reconfiguration agent is the agent controls the reconfiguration of the terminal. The inter-relationship with other functional module is shown in Figure 4.

Figure 4: Inter-relationship between the Reconfiguration Agent and other functional blocks

JRRM and the single RAT's RRM are captured within the concept of ARRM (Advanced Radio Resource Management), this works in the inner-loop of the overall functional architecture.

ARRM provides higher spectrum efficiency while conquering the typical problems, such as the signal attenuation, terminal noise, fast fading due to multipath phenomenon, shadowing, *Multiple Access Interference* (MAI) and other typical system related features, e.g., the mutual relation between interference strength and duration period given by link adaptation.

These typical problems challenge us from using radio resources efficiently. The radio resource is not only, by definition, the radio spectrum, but also realized in the real radio network as, access rights for individual mobile users, time period a mobile user being active, channelization codes, transmission power, connection mode, etc., that require the management functions being designed in different time scales. Furthermore, radio resources from different radio networks can be managed jointly in order to solve the encountered problems more effectively.

Besides the functions introduced specified by the local

radio resource management for a single RAT, the JRRM defined as a set of networks' or cell layers' controlling mechanisms that supports intelligent admission of calls and sessions; distribution of traffic, power and the variances of them, thereby aiming at an optimized usage of radio resource and maximized system capacity. JRRM mechanisms work over multiple radio networks or cell layers with the necessary support of reconfigurable/multi-mode terminals. JRRM is operated in a network which consists of several subnetworks or cell layers of a single radio network.

Figure 5 outlines the interworking among GSAM, LSEM, LSAM and ARRM. The GSAM allocate spectrum resource to the groups of RATs and involving entities including the primary operator and the secondary users. The LSEM interfaces the SAM_Agent dealing with the auctioning process. In each auction period, the LSAM allocate detailed spectrum brickworks to the selected RATs of the spectrum users for better spectrum efficiency, since the LSAM is aware of the radio context compared to the LSEM. ARRM makes most detailed spectrum allocation for the applied traffic. The frequency of ARRM activation is higher than the LSAM, can be around factor 10 or more. Upon the next auction, the LSAM will integrate the total spectrum used over time and report back to LSEM by balancing the payment w.r.t. the really used spectrum resource.

Figure 5: Interworking among GSAM, LSEM, LSAM and ARRM

I. Performance improvements

The different modules and technologies forming part of the E²R functional architecture for spectrum and radio resource efficiency have been individually evaluated and their potential gains have been identified. For each of the mechanisms (ASM, JRRM and DNPM) different techniques and algorithms have been investigated. Exemplars of results include efficiency gains for ASM in the range of up to 52% (for Dynamic Spectrum Allocation) and up to 144% for enhanced Dynamic Channel Allocation. For JRRM, a reduction of dropping probability of up to 85% could be achieved. Finally, applying DNPM, efficiency gains in the

area of 30-60% (depending on the specific traffic mix) were achieved in a scenario where W-LAN and UMTS systems provided voice and data services. These and further results are provided in detail in the E2R deliverable D5.4 [14].

IV. CONCLUSIONS

The migration of wireless communications beyond the third generation (B3G) necessitates research in converging systems, where many diverse functional capabilities cooperate over a global wireless access infrastructure. In this context, this paper has presented a functional architecture depicting the cooperation among three main research areas in reconfigurable systems. i.e. the ASM, the DNPM and finally the JRRM. It is expected that the definition of the functionality of the aforementioned modules will help in elaborating more on their interrelation capabilities, so as to serve as a basis for the overall end-to-end reconfiguration architecture.

Future related work includes more elaboration on the time scales of the functional modules as well as detailed study of the values of the operational parameters that need to be considered in the inter-working of the different modules. Moreover, careful consideration of the potential to elaborate on the usage of such functional architecture in B3G infrastructures operating in adaptive mode is also envisaged, so as to fully exploit cognitive networking technologies.

ACKNOWLEDGEMENT

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

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