ISSUES IN THE INTRODUCTION OF RECONFIGURABILITY IN WIRELESS B3G ENVIRONMENTS

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ABSTRACT

The wireless world is migrating towards the era of *Beyond the 3rd Generation* (B3G) wireless communications. A major contributor towards this convergence is *reconfigurability*, which provides technologies that enable terminals and network segments to dynamically adapt to the set of RATs, which are most appropriate for the conditions encountered in specific service area regions and times of the day. Reconfigurability poses requirements on the functionality of wireless networks. This paper presents challenges that have to be met, in order to realize the reconfigurability concept. The paper will present the views and work conducted in the context of the Working Group 6 (WG6), "Reconfigurability", of the WWRF.

1. INTRODUCTION

As globalization necessitates worldwide communication capabilities, the world of telecommunications is currently undergoing some radical changes, in order to meet the – continuously increasing – user demands. Wireless communications, which stand at the forefront of the technological revolution, comprise nowadays a multiplicity of Radio Access Technology (RAT) standards. Moreover, this set of discrete technologies is currently transforming to one global infrastructure, called *Beyond the 3rd Generation* (B3G) [1] wireless access infrastructure, which aims at offering innovative services, according to user demands, in a cost efficient manner. A major contributor towards this convergence is the *reconfigurability* concept [2].

Reconfigurability, an evolution of "software defined radio" [3], implies terminals and network elements (segments) that dynamically adapt to the set of RATs, which are most appropriate for the conditions encountered in specific service area regions and times of the day. RAT selection is not restricted to those preinstalled in the elements. On the contrary, missing components can be dynamically downloaded, installed and validated.

Reconfigurability poses requirements on the functionality of wireless networks. This paper presents challenges that have to be met, in order to realize the reconfigurability concept. The paper will present the views and work conducted in the context of the Working Group 6 (WG6) [4], titled "Reconfigurability", of the Wireless World Research Forum (WWRF) [5].

In particular, the rest of this paper is structured as follows. The next section introduces the areas that have to be addressed. These areas are discussed in sections 3 – 6. Finally, in section 7 concluding remarks are drawn. The identified areas are related to scenarios and requirements, suitable management protocol stacks, network support services, and appropriate network management and planning functionality.

2. WORK AREAS

For the effective deployment of reconfigurable networks, work in several areas is required. These are depicted in **Figure 1**.

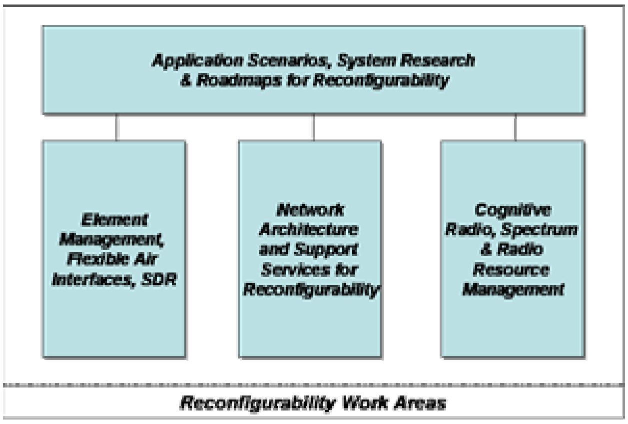

Figure 1: Reconfigurability work areas

First of all, the viability of reconfigurability is dependant upon business cases that justify the need for innovations in communication networks. In addition, application scenarios that depict specific facets of reconfiguration need to be addressed, in order to demonstrate the benefits gained by reconfigurability.

Second comes the management functionality required in reconfigurable equipment for realizing the vision of dynamic, efficient and transparent adaptation of terminals to changes in circumstances. Moreover, flexible protocol stacks are to be developed, requiring the minimum possible alterations between successive reconfigurations.

Third, innovative network functionality is needed for the support of reconfigurability, in order to identify triggers that necessitate reconfigurations, to implement reconfiguration decisions and to minimize the requisite signaling load.

Last but not least, management functionality is required for tackling problems that fall in the realm of reconfiguration decisions, as well as for convincing network operators that reconfigurability can reduce the cost for network deployment.

The aforementioned work areas are further analyzed in the sequel.

3. APPLICATION SCENARIOS, SYSTEM REQUIREMENTS, TECHNOLOGY ROADMAPS

The commercial success of reconfigurable networks lies upon their ability to offer innovative services to users, with a cost-effective manner. In order to achieve this, attention must be placed upon typical application scenarios envisaged to occur in a reconfigurability context, depicting diverse facets of reconfiguration. These scenarios will lead to the identification of the system architecture needs, in order to facilitate the deployment of reconfigurability [6].

After a detailed process of analysis and selection, scenarios have been merged identifying the following three families of scenarios:

- *Ubiquitous Access*
- *Pervasive Services*
- *Dynamic Resources Provisioning*

Ubiquitous Access is mainly targeted at increasing the worldwide access to services. It relates to the support of the user who switches on his device in a new wireless environment to which he has not been previously connected. Roaming is a particular example of this scenario, and the increase of roaming possibilities granted by the reconfigurability is highlighted.

The purpose of the *Pervasive Services* scenario is to stress the need for reconfigurability when several radio access technologies are present in the wireless environment. Indeed, to properly use these different access technologies, the reconfigurable equipment needs many capabilities like system discovery, protocol reconfiguration and vertical handover

Dynamic Resources Provisioning aims at underlining that a dynamic reconfiguration of the terminal and of network elements improves the bandwidth for the users thanks to better adapted radio interfaces, as well as additional spectrum. In this case, the protocol stack must be updated in the terminal and in the network. Consequently, the different communication systems covering such areas, must adapt to the load and services variations.

The aforementioned three families of scenarios represent a significant step forward in terms of identifying where reconfigurability can play a major role in the delivery of services to the user and also in the optimization of the network resources to achieve the best results.

Careful analysis of these scenarios has incurred the list of requirements, which constitutes the specification of the reconfigurability framework that has to be elaborated. The various requirements are intended to be satisfied by functions distributed on the various elements constituting the system. Such requirements refer to (i) the definition of minimum performance criteria for service provision, (ii) the equipment capability to change its configuration including operating parameters by means of software autonomously and securely, (iii) the protection from the possible interference coming from badly reconfigured equipment, (iv) the efficient management of the end-to-end reconfiguration and (v) other basic mechanisms, such as Service Adaptation, Vertical Handover, Service Provision, System Monitoring, Dynamic Resource Management and Spectrum Transfer.

The identification of requirements raises a question on the vitality of reconfigurability, with respect to the specification of a plausible roadmap for the deployment of reconfiguration applications into equipment and by extension into networks. Such a roadmap may serve as a guide in anticipating evolution, identifying important problem areas and if possible contribute to appropriate organizations in meaningful topics. As the deployment will be incremental; in between deployment phases experimentation is certainly needed. System prototyping will be a valuable approach in order to concretely demonstrate solutions into a smaller scale before their application in a larger scale. Such experimentation and prototyping could be part of R&D projects investigating future telecom systems.

4. ELEMENT MANAGEMENT, FLEXIBLE AIR INTERFACES, SDR

As identified in section 2, one of the targets of the reconfigurability research framework is to present a concept for a Management and Control System that enables elements to operate in an end-to-end reconfigurability context [7]. The main idea of this concept is a clear separation of the management and the control functions. A high level view of the management and control of equipment in an end-to-end reconfigurability context is depicted in **Figure 2**.

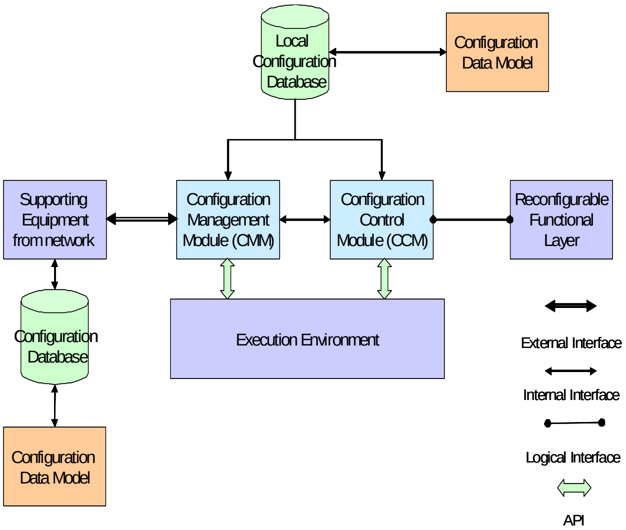

Figure 2: High Level view of the management and control of equipment in an E2R system

The proposed framework consists of two main modules:

- The Configuration Management Module (CMM)
- The Configuration Control Module (CCM)

The Configuration Management Module (CMM), which is a functional entity within the equipment (terminal, base station/access point or network), that manages the reconfiguration processes according to, specified semantic, protocols and configuration data model (which may be stored in distributed configuration data-base system). From the equipment perspective the various CMMs also interact among themselves as well as with supporting equipment entities within the network, through an external (transparent) interface. The Configuration Management Module (CMM) is responsible for managing the distributed controllers, which will initiate, coordinate and perform the different reconfiguration functions such as monitoring and discovery, software download, mode selection and switching (multimode/multi standard), security. The CMM consists of the following functional entities:

"Interfaces with the Network Support Services" (CMM_IfNss). This functional entity is responsible for network-initiated re-configuration and other services while the terminal is in on-line idle mode. This module will receive messages from the network, and it may activate other modules to start configuration or other actions in the terminal. The network-supported services can issue reconfiguration commands to the CMM. Moreover, supporting information can be exchanged between the network support services and the CMM, so as to consolidate on the best reconfiguration decisions.

"Monitoring and discovery" (CMM_MD). The role of this entity is to identify the available networks in a certain area and to monitor their status. It acquires information on the context in the environment of the device and takes into account data from multiple CCMs.

"Negotiation and Selection" (CMM_NS). This functionality is targeted for the negotiation of offers with the various available networks. It selects the most appropriate available network taking into account information such as the user and terminal profile and the offers negotiated with the networks. The user profile specifies services, QoS levels, cost levels etc. The terminal profile specifies the capabilities, configurations present at memory, etc. The network offers specify the services offered, the QoS levels supported, cost information etc. The goal of the negotiation functionality is the refinement of parameters (e.g. related to network offers). For this purpose, standard negotiation protocols need to be adopted and customized.

"Configuration downloads" (CMM_Dwnld). This functional entity provides the capability to perform downloads of the different components that may be required for the reconfiguration process. In other words, it undertakes the management of the downloading procedure. The downloaded information could be a whole protocol function in form of components or a parameter of a component. The downloading procedure encompasses stand-alone or distributed mechanisms that are required in order to communicate with the software provider.

"Profiles" (CMM_Prof). This functional entity provides configuration profiles information on applications, user classes, equipment classes/capabilities and configuration data models. The CMM_Prof is able to compare profile of the current configuration and the proposed future configuration in order to recognize the absence of a particular function needed for activating the target communication system, protocol stack or application for each level respectively.

"Security" (CMM_Sec). This module supports the security functions required during the reconfiguration process within the different layers.

"Decision Making and Policy enforcement" (CMM_DMP). This entity communicates with the Reconfiguration Management Plane (RMP) entity. It interacts with the Reconfiguration Management Plane (RMP) to provide information and mechanisms for the decision of reconfiguration actions. It enables the provision of reconfiguration policies and actions throughout the network and locally in the network nodes and equipment. The interface between the RMP and the CMM_DMP mainly supports context and policy management procedures. Policy-based mechanisms and procedures are being implemented and performed by entities that are dedicated to mode selection and switching dovetail the mechanisms of RMP.

"Reconfiguration Installation" (CMM_Instl). This function is to provide, by interacting with the CMM_Dwnld and CMM_DMP functional entities the means for configuration representation and configuration deployment, which involves configuration download, validation, installation and switching.

"*Event handler" (CMM_Evnt).* This entity enables the coordination of the different reconfiguration triggers, which activates scheduling and implementation procedures through the corresponding CCM according to the target reconfiguration. Events may be received from within the terminal (e.g. discovering new network: CMM_MD, or completing configuration software download: CMM_Dwnld), or externally (e.g. receiving a message via CMM_IfNss)

The Configuration Control Module (CCM), which is a supporting entity responsible for the control and supervision of the reconfiguration execution. This is done using specific commands/triggers and functions of a given layer or a given execution environment. Three main layers are considered here: application, protocols stack (L2 – L4) and modem (L1). The Configuration Control Module (CCM) initiates, coordinates and performs the different reconfiguration functions. The CCM consists of the following functional entities:

Configuration Control Module – Application Layer (CCM_AP), that provides the interface between the CMM and the application layer.

Configuration Control Module – Protocol Stack layer (CCM_PS), that provides the interface between the CMM and the protocol stack of a protocol suite like TCP/IP (e.g., layer 3/4, namely TCP/IP) or/and of a communication standard (e.g. layer 2/3 of UMTS/WLAN standard). This entity enables the addition of a complete new protocol function to the equipment and the parallel operation of this new protocol function with the existing functions.

Configuration Control Module– Reconfigurable Modem (CCM_RM), that provides the interface between the CMM and the physical layer resources.

Other entities closely related to equipment management are the Execution Environment and the Reconfigurable Protocol Stack framework (or Reconfigurable Functional Layers).

The Execution environment is the means for providing the basic mechanisms required for dynamic reliable and secure change of equipment operation. The execution environment aims to offer a consistent interface to the equipment reconfiguration manager in order to apply the needed reconfiguration actions. For reconfigurable equipment, reconfigurable components need to be used. Such components are programmable processors, reconfigurable logic, parameterized ASICs (offering software control on their parameters). The Execution Environment sits on top on this hardware platform and offers basic mechanisms enabling the exploitation of the reconfigurable hardware components.

The Reconfigurable Protocol Stack Framework is an open protocol stack framework, which can be used to support several RATs with diversified protocols and protocol functions. This implies an architecture that supports dynamic insertion and configuration of different protocol modules in a common manner taking into account the resources and capabilities of the target devices.

Furthermore, as reconfigurability of SDR equipment is widely seen as one of the enabling technologies for the communication systems beyond 3G, this working area aims at outlining the issues and technological problems of reconfigurable systems and endeavours the definition of a "Reference Model for Reconfigurable SDR Equipment and Supporting Networks'. The reference model includes the multitude of different radio transmission and access technologies and encompasses System and Network (including core and access network/base stations), hardware issues in both RF & BB side and data & control/management interfaces between the various building blocks of the reconfigurable environment.

5. NETWORK ARCHITECTURES AND SUPPORT SERVICES FOR RECONFIGURABILITY

Reconfigurable radio may well be used together with traditional network infrastructure, which does not provide sufficient support for the features of re-configurable radio. However, the full benefits of SDR show up only if the network infrastructure takes into account the specifics of a particular terminal and provides support for it [8].

Network support for reconfigurable entities requires the definition of appropriate functions in existing network elements or separate reconfiguration entities (e.g. reconfiguration proxies). The definition of reconfiguration signaling between reconfiguration functions and reconfigurable entities as well as their interworking with the control plane and interactions between reconfiguration and control plane are other key points. Based on network architectures derived, reconfiguration signaling between entities for installation, de-installing and verification will be also identified. Intelligent and self-learning protocols dependent on the reconfiguration context will be evaluated. Reconfiguration security for secure download, installation, verification and fault management must be addressed to ensure a reliable operation and to satisfy regulatory demands for radio software. A framework for secure access to reconfiguration functionality by operators, manufacturers and 3rd parties must be developed. Further, active network environment for management of reconfiguration will be studied.

The emerging network infrastructure is targeting at support for most of reconfiguration requirement. In particular, the subsequently listed issues have to be taken into account in the design of network elements for future mobile networks:

- The distribution pattern of terminal and user-related information (profiles) is changed compared to conventional networks.
- Software download support must be integrated into the network infrastructure.
- Integrated usage of different radio technologies available in the same area should be enabled.
- Focus on fixed radio standards is likely to be reduced in favor of greater flexibility.
- Openness of network infrastructure has to be increased in order to allow device sharing, RAT sharing and resource sharing between different network operators.
- Reconfigurability of the network infrastructure has to be provided in order to obtain even more benefits of SDR technology.
- Secured reconfiguration has to be supported for a safety radio environment.

In addition, the reconfiguration management architecture will provide mechanisms for the dynamic planning and management of heterogeneous, coupled, and multi-standard radio access networks. It will be investigated whether with the support of network reconfigurability, cost for network deployment can be decreased while significantly enhancing efficiency of user traffic handling.

6. COGNITIVE RADIO, SPECTRUM AND RADIO RESOURCE MANAGEMENT

The future of telecommunications has been anticipated as an evolution and convergence of mobile communication systems and IP technologies, to offer a great variety of innovative services over a multitude of Radio Access Technologies (RATs). To implement this vision, it is mandatory to embrace the requirements with respect to the support of heterogeneity in wireless radio technologies accesses, services, mobility, devices and so on. Consequently, there are basic principles that must be respected, in order to render composite reconfigurable networks commercially successful. These lie in the effective management of the available resources, i.e. (i) in a more efficient utilization of the available spectrum (ii) a joint management of radio resources belonging to different RATs with fixed spectrum allocation and (iii) an intelligent network planning process [9].

Radio Resource Management (RRM) is a complex process, but necessary for the deployment of B3G networks. It consists in managing dynamically resources like spectrum, as well as allocating traffic dynamically to the RATs participating in a heterogeneous, wireless access infrastructure. Consequently, we can look at RRM as a superset of Spectrum Management and Joint Radio Resource Management (JRRM). This is the starting point for the decoupling of the general problem referring to the whole reconfiguration management process.

Spectrum Management

The term reconfiguration applies not only to the selection among a set of available RATs in the service area, but also to the appropriate configuration of the resources utilized, i.e. careful selection of the operating frequency band. Such issues imply that there is need for flexible managing the spectrum, as the current spectrum allocation, fixed by nature, would not allow such actions as allocating frequency bands to different RATs dynamically. However, the coexistence of diverse technologies which form part of a heterogeneous infrastructure has brought about the idea of flexibly managing the spectrum. This implies that no more fixed frequency bands are guaranteed for RATs, but through an intelligent management mechanism, bands are allocated to RATs dynamically, in a way that the capacity of each RAT is maximized and interference is minimized.

Furthermore, there is a tight relationship between spectrum management and cognitive radio. Flexible spectrum management is needed for wireless devices that operate in either the unlicensed band or the unlicensed band or both as Illustrated in Figure 3.

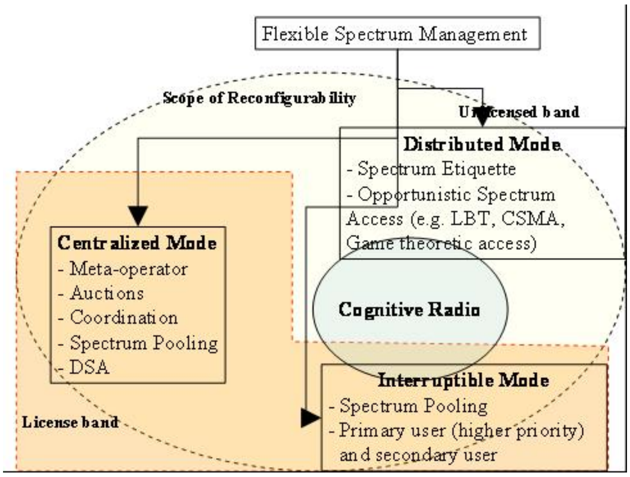

Figure 3: Technical Scope on Spectrum Management Approaches

Cognitive radio will provide the technical means for determining in real-time the best band and best frequency to provide the services desired by the user at any time. In this section, even though separate sub-sections are provided for technical and regulatory aspects of spectrum management, the two are closely intertwined

Joint Radio Resource Management

This term refers to a set of network's 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. These mechanisms work simultaneously over multiple RATs with the necessary support of reconfigurable/multimode terminals.

Furthermore, the ever growing demand for high-speed access to all kinds of telecommunication systems has rendered necessary the reconsideration of traditional network planning methods. Taking into account that the advent of composite reconfigurable networks has become an inseparable part of almost every communications conference and journal, dynamic network planning is essential in order to handle the alternations that take place in frequent time periods, with respect to the demand pattern in a specific geographical area. So, the goal of dynamic network planning is to reduce the cost for network deployment, through the selection of the appropriate RATs for operation at different time and space regions. Dynamic Network Planning is considered as a subset of a more general framework, namely Dynamic Network Planning and Management (DNPM), i.e. a framework dealing with planning and managing a reconfigurable network. The interrelations between DNPM, RRM, Spectrum Management and JRRM are depicted on **Figure 4**:

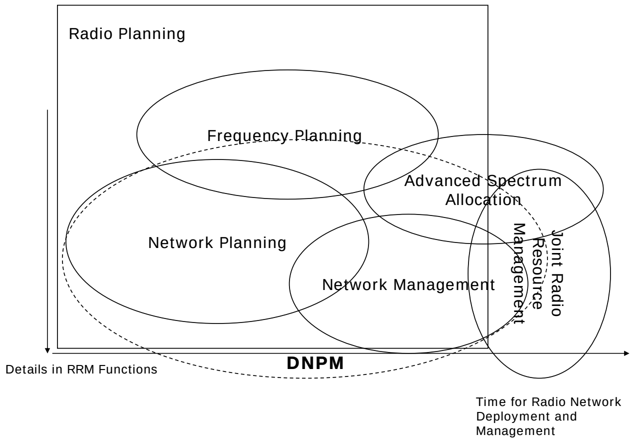

Figure 4: Radio planning related techniques

7. CONCLUSIONS

This paper presented the guiding research framework of WWRF Working group 6 (WG6, "Reconfigurability"), with respect to the development of innovative ideas for the facilitation of the deployment of reconfigurability. The work has evolved in a certain way: First, the application scenarios were defined and the system requirements for reconfigurability were identified. Then, the overall approach was split in the element reconfiguration, the network support for reconfigurability and the efficient management of radio resources.

Recapitalizing the approach followed, it must be noted that reconfigurable networks will become commercially successful, only if (i) new applications are introduced and massively adopted (if offered at acceptable costs) and (ii) the required quality of service (QoS) and capacity levels are achieved in a cost-effective manner. The Working Group 6 of WWRF aims at facilitating this deployment, by bringing to every field of human initiative the full benefits provided by reconfigurable networks.

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