E^2R PROJECT: MAJOR EUROPEAN INITIATIVE ON RECONFIGURABILITY

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ABSTRACT

The End-to-End Reconfigurability (E^2R) research aims at bringing the full benefits of the valuable diversity within the radio eco-space, composed of a wide range of systems such as cellular, wireless local area and broadcast. Benefits of end-to-end reconfigurability could be enabled if and only if the reconfigurability is considered simultaneously at all layers, for all involved actors. Indeed, the most advanced reconfigurable equipments will bring very limited advanced features if the network or the services are not designed to support them. Similarly, reconfigurable networks will bring limited advantages if designed without considering reconfigurable equipment capabilities. E^2R is seen by many actors of the wireless industry as a core technology to enable the full potential of beyond 3G systems. It has the potential to revolutionize wireless just as the PC revolutionized computing. This paper presents the overall E^2R project research and the main fields of investigations across the different technical workpackages in the first 2-year phase of the project that started in January 2004. The paper includes the initial results and the expected impacts of end-to-end reconfigurability.

1. INTRODUCTION

The key objective of the End-to-End Reconfigurability (E^2R) [1] project is to devise, develop and trial architectural design of reconfigurable devices and supporting system functions to offer an expanded set of operational choices to the different actors of the value chain in the context of heterogeneous mobile radio systems. Innovative research, development and proof of concept are sought in an end-to-end aspect, stretching from user device through all system levels including Internet protocol and services. Furthermore reconfigurability support intrinsic functionalities, such as management and control, download support, spectrum management, regulatory framework and business models complete the project scope. This paper introduces the overall project research and the main fields of investigations across the different technical workpackages: E^2R system research, equipment management, network support for reconfiguration, radio modem reconfigurability, evolution of Radio Resource Management and spectrum management, and E^2R evolutionary prototyping environment.

2. E^2R SYSTEM RESEARCH

The aim of the system research for end-to-end reconfigurability is to aggregate the technical, business and regulatory visions from the different actors of the telecommunications system (from user to service provider) and this, across the different layers of the system, from physical layer to application layer and across the different equipments. To provide this overall vision, realistic and futuristic scenarios have been elaborated in order to enable E^2R requirements capture.

Building on the scenarios, relevant associated requirements have been identified. Those results were analysed to elaborate a generic system architecture enabling end-to-end reconfigurability architecture. Results will also be valuable to address the current regulatory framework (e.g. material conformance, security, spectrum…) and evaluating the impact of the scenarios on security, privacy, EMC, frequency sharing rules, responsibilities… These families of scenarios have been derived as a result of the analysis of the merged scenario contributions from the different workpackages of the project [2]. They are grouped in three main families representing a common thematic and corresponding to an anticipated coherent timeframe of technical availability: (1) ubiquitous access, (2) pervasive services, and (3) dynamic resources management. The E^2R high-level scenarios are describing some general context highlighting the benefits of reconfigurable equipment without describing the underlying technologies neither detailing the various possibilities as it is done in the other technical workpackages. In parallel of this scenarios creation, the business path regarding economical paradigm is elaborated. The purpose is to depict business models regarding the technological roadmaps, and to suggest a coherent business path with the technology evolution towards reconfigurability for each identified actor of the value chain.

The impact on the end-to-end system in providing communications and the requirements for supporting each family of scenarios is also addressed. This is achieved with a particular focus on the various parts involved in the reconfiguration of the communication protocol in order to cover all the layers. Moreover, all types of reconfigurations are captured: static, quasi-static or dynamic reconfiguration, on-demand/periodic reconfiguration, partly/complete reconfiguration, and run-time/offline reconfiguration. These scenarios, and the requirements implied by them, are the entry points for the definition of overall system architecture. The aim of the E^2R architecture is to describe a framework support for reconfigurability. This framework is obviously supposed to be distributed over various parts of the system. The methodology tries to avoid the choice of a technological solution for this framework. So, the purpose is to be techno-agnostic.

Finally, end-to-end reconfigurability will need a very flexible regulatory approach to develop its full potential. Major changes in the regulatory framework for telecommunication may be required. E^2R aims to significantly contribute to this process. This will be done, by first of all addressing the current regulatory framework and the associated limitations and boundaries, and evaluating the impact of the E^2R scenarios.

3. EQUIPMENT MANAGEMENT

Reconfigurable equipment is the cornerstone for the implementation of SDR and reconfiguration capabilities in the terminal and other network equipment. The required functionalities to be introduced in the equipment expand the complexity and pose additional requirements in managing this complexity. Therefore, the introduction of management entities for handling this complexity becomes imminent.

In the framework of E^2R, a management architecture and respective functionality are proposed for the equipment management. The Configuration Management Module (CMM) [3] has interfaces to the different reconfiguration layers (internal), and also to the network support services (external). The Configuration Control Module (CCM) has to perform and control the reconfiguration action for each layer. Within the framework of this research work, the following layers are considered: (1) Modem layer, (2) Protocol Stack layer and (3) Application layer. The interfaces to the different reconfiguration layers are realized through the CCMs (controllers):

- The Configuration Controller Module – Application Layer (CCM_AP) provides the interface between the CMM and the application layer. The interface offers monitoring and configuration functionality,
- The Configuration Controller Module – Protocol Stack (CCM_PS) layer provides the interface between the CMM and an arbitrary protocol layer (e.g., layer 3/4, namely TCP/IP). The interface offers monitoring and configuration functionality,
- The Configuration Controller Module – Reconfigurable Modem (CCM_RM) provides the interface between the CMM and the layer 1, which support the wireless communication. The interface offers monitoring, configuration, and environment discovery functionality.

CMM is required to manage the distributed controllers, which will initiate, aggregate and coordinate the different reconfiguration functions such as monitoring and discovery, software download, negotiation and mode selection (multimode/multi standard), security. The CMM comprises the following modules/entities:

- The entity “Interfaces with the Network Support Services” is responsible for network-initiated reconfiguration 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 entity “Monitoring and discovery” can conduct more complex assessments, taking into account data from multiple CCMs. The entity acquires information on the context in the environment of the device,
- The entity “Reconfiguration Negotiation and Selection” is another core module of the CMM. It deals with the identification of the reconfiguration pattern to be followed. Different algorithms, simple or more sophisticated, can be considered,
- The entity “Configuration Downloads” provides the capability to perform downloads of the different components for the reconfiguration process,
- The entity “Profiles” provides configuration profiles information on applications, user classes, equipment classes/capabilities and configuration data models,
- The entity “Security” supports the security functions during the reconfiguration process within the different layers,
- The entity “Reconfiguration Installation” is a core entity of the CMM, which supports the different functions. It can be decomposed to numerous components. One component should provide the means for configuration representation. Moreover, there is need for components, which will provide the means for configuration deployment,
- The entity “Decision-Making and Policy Enforcement” is the module that communicates with the main reconfiguration management plan entity. This interface supports mainly context/policy management procedures.

Given the complexity of the reconfiguration process, there is a need of reconfiguration event handler, which would enable the coordination of the different reconfiguration triggers, scheduling, procedures and implementation. Events may be received from within the terminal, or externally.

The main results envisioned from the introduction of the proposed functionality are: (1) the support of reconfiguration actions at all layers, (2) the support of flexible equipment management mechanisms, (3) the evolution of cognitive systems, and (4) the evolution of equipment self-awareness and adaptation. Therefore, it is important to introduce such an Equipment Management Architecture, in order to provide a framework for advanced, policy-based equipment reconfiguration.

4. NETWORK SUPPORT FOR RECONFIGURABILITY

Reconfigurable systems are expected to realize the main requirements for flexibility in Beyond 3G systems. More significant than the bit rate foreseen for Beyond 3G systems appears to be the advanced capabilities expected, such as the support of smaller cells, self-planning dynamic topologies, full integration of IP, more flexible use of the spectrum and other resources, as well as user location usage. Bandwidth issues will have to be considered under different perspectives such as radio resource management, for example intersystem handovers might be based on changing quality requirements or swapping services during communication. Service requirements are affecting the overall design and planning, as it will become more and more important to deliver the right information at the right time and to the right place. Content and applications become of high importance.

In the framework of E^2R, a suitable reconfiguration management plane stretching from user interfaces/interactions, services, networks to terminals is proposed [4]. Adaptation functions, located in the network, supporting reconfigurations will have an impact on end-user service provisioning and the cost of network operation and maintenance. The Reconfiguration Management Architecture introduced during the scope of E^2R will facilitate inter-operator negotiations, involving exchange of information that is required for terminal reconfiguration and advanced radio resource management, provide mechanisms for the dynamic planning and management of heterogeneous, coupled, and multi-standard radio access networks. The identification of the reference architecture and the network requirements is the first step in the definition of the capabilities that the network has to implement for supporting the terminal reconfigurability. Key aspects of the reconfiguration process are:

- Distribution of the information and control functions in the network,
- Description of the reconfiguration process with focus on the identification of the functions involved in each step and their interaction,
- Definition of interfaces between network elements involved in the reconfiguration process,
- Mobility management during software download,
- Functional partitioning supporting dynamic network management,
- Fault tolerance and reversal processes.

To enhance the performance and to accelerate the reconfiguration process, the description of a possible distribution of the relevant information such as the software to be downloaded and the relevant information contained in the communication profiles of the mobile scenario (user, terminal, network and service profile) has to be provided. The description of these profiles focuses mainly on the definition of the role of each profile entity in terms of classes of information stored and involvement of each profile during the reconfiguration process. Likewise, the high level description of the signalling between reconfiguration management elements associated to the request of information should be provided.

Identification of the functions involved in the reconfiguration phases and their mutual interactions are other relevant aspects for investigations, in particular, the identifications of interfaces for reconfiguration management elements and the interactions between the functions in the reconfiguration management element. The 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 signalling 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.

The Reconfiguration Management Architecture will facilitate integration of heterogeneous RAN technologies, involving exchange of information that is required for terminal reconfiguration and advanced radio resource management. The Reconfiguration Management Architecture will provide mechanisms for the dynamic planning and management of heterogeneous, coupled, and multi-standard radio access networks. It is foreseen that to solve the complicated reconfigurable network management problems, the real time system performance management with the support from terminal monitoring functions, secured and reliable network management functions are of great importance. To reach an optimal architecture solution and management functions, the following points will be intensively investigated:

- Further developments of the E^2R architectural solution and the interfaces. The apportionment of functionality between the equipment and the network will be explored in more details,
- Mobility management concepts during software download will be refined and adapted, and discovery mechanisms for available network and terminal capabilities will be defined. The definition of suitable profile architecture for policy-based support for reconfiguration comprises another target working area,

- The requirements of procedures for network reconfiguration related to Radio Access Technology selection and partitioning will be examined and - motivated by interworking concepts for Radio Resource Management - the necessary control plane functionality will be enhanced and reconfiguration/download functions will be specified,
- Concepts for re-locating network functions and the associated signalling comprise topics of paramount importance. The definition of procedures for adaptive network configuration and planning.

In a final step, an integrated framework for network support for reconfiguration, consisting of interfaces and open APIs, network support functions and signalling, enabling environment will result with a concrete assessment of security solutions adapted to the reconfiguration architecture.

5. RADIO MODEM RECONFIGURABILITY

As stated above, reconfigurable networks will bring limited advantages if designed without considering reconfigurable equipment capabilities. Reconfigurability is therefore required within the complete equipment, from the physical layer up to the higher layer. The layer 1 functionality in this case is the most challenging part, as it has to tightest requirements in terms of power consumption, latency and data rates. Therefore physical layer architecture has to be developed, which meets the functional requirements derived from different scenarios and standards and offers reconfiguration capabilities in a broad range. The physical layer architecture of the reconfigurable modem consists of a set of functional elements (RF-frontend, communication, digital processing) forming the upper layer of a system of different levels of hardware abstraction.

At this level, functional elements appear as reconfigurable modules implementing a specific functionality (e.g. down-conversion, modulation, and decoding). A specific Configuration Control Module (CCM) configures such modules and also manages the communication resources between the processing elements to guarantee the required functionality and maintain the required data throughput. Downloading of object code to programmable resources and bit-streams to reconfigurable logic as well as setting parameters of hardware accelerators has to be performed at a lower level of abstraction supported by low level device drivers in order to comply with the principle of hardware abstraction and thus platform independence. The CCM is a unique component inside a reconfigurable physical layer. It has to fulfill a set of requirements, given in the following list [5]: Platform independent behavior, dynamic downloading of software/configurations, power conscious, standard interface to the CMM, seamless and partial reconfiguration, reliable, predictable and secure configuration, and configuration/control of all stages in the receive and transmit path.

A set of abstraction layers has been defined, which is supporting the CCM in translating the platform independent reconfiguration requests being on a functional level into a platform dependent implementation view, which is proprietary to the manufacturer. On the highest-level, a service API has been defined, which is providing access to certain reconfiguration capabilities. These interfaces [3] are:
- Primary Configuration Control Interface between the CMM and the CCM will be used set-up a new configuration (i.e. system initialization),
- Secondary Configuration Control Interface between the CMM and the CCM. This interface supplies a set of functions unique to the currently configured primary interface. It is the main interface for protocol layer configuration (e.g. RRC/RLC/MAC),
- The Capability Interface allows the CMM to determine what configurations the underlying layer is supporting. This interface has to be used, in order to decided whether an intended configuration (e.g. UMTS/FDD with HSDPA) is supported from the equipment,
- The Database Interface provides access a local database. This database will contain specific configurations and their properties,
- The Auxiliary Service Gateway allows an optional customized and proprietary interface to the CCM to be created. Typically this might be used for adaptation or cross-layer optimization.

The importance of the proposed architectures, the introduced abstraction layers and interfaces, is that this will create and provide well-defined methods to access all available reconfiguration capabilities of the terminal in a uniform manner, without any knowledge of the actual implementation. Therefore an exchange of capability parameter on a functional level (e.g. supported frequency ranges, bandwidths, code rates, etc.) is possible, bringing the network as well as the user into a position to optimize the equipment and therefore the network according given profiles. From concept point of view, there is no difference, whether the reconfiguration is done for the physical layer, the protocol layer or the application layer. There is always a mapping of functionality onto a hardware and software components (of course with a different ratio between SW and HW functions). Therefore it can be expected that the general proceeding with the physical layer CCM is transferable towards the other CCMs.

6. EVOLUTION OF RRM AND SPECTRUM MANAGEMENT

E^2R undertakes extensive research towards dynamic network planning and flexible network management, with the aim to make more efficient use of the classically scarce resource of radio spectrum. The section describes the approach and methodologies for flexible spectrum management, and provides a description of a comparison between different spectrum assignment schemes.

The composite radio concept assumes that different radio networks, e.g., GPRS, UMTS, BRAN/WLAN, DVB, etc. can be cooperating schemes within a heterogeneous, wireless-access infrastructure. When properly applied, users will be directed to the most appropriate and most efficient Radio Access Technologies (RATs), depending on performance, load and availability criteria at different service area regions and time zones. Reconfigurability will be one of the main facilitators to implement composite radio systems, the technology provides essential mechanisms that enable terminals and network elements to dynamically (transparently and securely) select, and adapt to, the set of RATs available and appropriate. Therefore, the development of mechanisms for dynamic planning and management of heterogeneous, coupled and multi-standard radio access networks that can flexibly access and share resources to balance the load is required. This includes investigations into whether flexible network reconfiguration decreases the cost for network deployment, while increasing the efficiency of resource usage.

Reconfigurability will allow the deployment of Dynamic Network Planning and Management (DNPM), yet its use will depend on the dynamic features of user traffic, expense comparison of the classical methods in operating radio networks with DNPM and in the heterogeneity of radio networks. DNPM consists of two phases; the planning phase and the management phase. During the planning phase, the feasibility of setting the radio interfaces; location of base stations; antenna patterns; coupling structure among sub-networks; policy of Joint Radio Resource Management (JRRM) are being considered. Yet during the management phase, a two layer reconfiguration (applicable in both network and terminal side) will be performed to implement the planned changes in the allocation of resources. The mechanisms investigated include "function reallocation among network elements" and "autonomous selection of proper RAT associated with optimal configurations of frequency bands". Mechanisms and signaling for such "self-tuning" RAN's are being designed in the course of E^2R project [5].

On the spectrum management side, some regulation authorities investigate approaches that may allow more flexible spectrum allocation practices. The investigations include following topics: (1) the extend of spectrum-sharing, (2) range of flexibility in spectrum assignment, and (3) temporary usage rights versus permanent spectrum usage rights. The authorities also investigate the type of possible future spectrum owners, to determine who and how ownership of licenses can be obtained. This includes distribution of new licenses, licenses auctioning and renewals, role and usage/temporal lease of governmental or civil held spectrum. These topics are of major impact to the spectrum sharing coordination process for flexible spectrum management.

Expecting the regulatory schemes for spectrum management to undergo a review, and anticipating moves and changes from the current rigid schemes towards flexible spectrum assignment, the E^2R projects investigates suitable algorithms for such flexible assignment. This involves identification and development of new methodologies for the spectrum management with the aim to further increase the spectrum efficiency and to optimize its usage. As previous research has shown, usage optimization can be achieved when a fragmented or even full "Flexible Spectrum Management (FSM)" approach based on Spectrum Brokerage (SB) is considered. Spectrum Brokerage (SB) is based on the identification of methods and mechanisms for more marked based spectrum policy approaches governing both spectrum and equipment sharing.

Whereby the Spectrum Brokerage (SB) principle treats spectrum as being a tradable good similar to stocks or real estate, etc. Spectrum Brokerage will provide the mechanisms for the decision making about who should have access for a chunk of spectrum, the actual management however must consider also the technical issues like interference avoidance between spectrums not spatially or temporally separated. The (Full) Flexible Spectrum Allocation approach pursued in E^2R investigates and defines optimized processes for spectrum management. The techniques are based on the methodologies for temporal and spatial allocation of spectrum. And first steps towards full Flexible Spectrum Allocation include the lessons learnt from the research into Dynamic Spectrum Allocation (DSA) of the DRiVE and OverDRiVE projects respectively. The FSA approach extends the DSA concepts, whereby particular focus is on the identification of guard bands and the definition of algorithms to minimize their usage (i.e. mixed spatial and temporal allocation algorithms). The FSA scheme directly impacts the Network Planning mechanisms, the detailed relationship between the two topics will eventually be investigated and, where necessary, algorithms will be modified to achieve the best possible network coverage and the best possible system efficiency.

7. E^{2}R PROTOTYPING ENVIRONMENT

In order to validate the various outcomes of E^{2}R, and also for benefiting of most up-to-date development in the reconfigurability area, the E²R project includes a prototyping environment. As reconfigurability is a straightforward enabler of a true seamless mobility experience, such prototyping environment serves as incubator for the definition of the services of the coming era of mobile telecommunications. Moreover, although several experimentations have been set-up within past projects, they focused on a specific aspect of the reconfigurability: modems, services, RF etc... There was no end-to-end prototyping platform for validating the end-to-end principles. Hence the work on specifying, developing and integrating the proof of concept has as additional goals to demonstrate end-to-end reconfigurability features, to provide an open, flexible and evolutionary experimental environment for anyone who wants to test and assess services; or technologies related to the reconfigurability domain.

The prototyping environment is build around several components:

- A GPRS experimental network infrastructure provided by Motorola Labs, which can evolve to support any emerging cellular systems, such as EDGE, UMTS,
- A UMTS-TDD software radio platform. The PC-based testbed of Institut Eurecom is implemented using a hard real-time micro-kernel known as RTLinux, running beneath the Linux operating system, for providing real-time end-to-end functionality. The current setting comprises: a BTS and a mobile terminal, real-time duplex, uses the UMTS/TDD transmission/reception mode, and a protocol stack that allows IP connectivity,
- A multimode integrated terminal, which on one hand is a general-purpose mobile computer, and on the other hand provides multiple communication channels for the operating system and for the applications that are executed on it,
- A middleware and service platform inherited from IST MOBIVAS project. This platform addresses a variety of issues related to provision of value-added end-user services in 3G and beyond mobile environments. The platform acts as a single point of contact for end-users as well as value-added service providers (VASPs) and provides several functionalities,
- Components of the shelves terminals such as laptop with multimode capabilities (e.g. GPRS/WLAN) or including alternative radio access technologies such as digital video broadcast (DVB). This latter technology is likely to become of high interest due to the recent effort in porting the DVB standard to mobile device within the DVB-H group.

All these components are integrated around an IPv4 or IPv6 backbone, in order to target modules independent of the IP protocol version. The first demonstration scenario foreseen is entitled “Software upgrade on the road”. It consists on upgrading the software of a radio terminal in a car while driving. Users in the car will hence have better quality of services after entering the car thanks to the software upgrade. Seamless mobility from and out the car will be shown.

8. CONCLUDING REMARKS

This paper presented the overall End-to-End Reconfigurability (E^{2}R) project research and the main fields of investigations across the six technical workpackages, including the initial results and the expected impacts. E^{2}R is seen by many actors of the wireless industry as a core technology to enable the full potential of beyond 3G systems, having the potential to revolutionize the wireless world just as the PC revolutionized computing.

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