END-TO-END RECONFIGURABILITY (E^2R): ENABLING INTEROPERABILITY, MANAGEMENT AND CONTROL OF COMPLEX HETEROGENEOUS SYSTEMS

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ABSTRACT: The objectives of the End-to-End Reconfigurability (E^2R) research project are to bring 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), and 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. The E^2R project will help operators to better exploit their investments on infrastructures and terminals and ensure that the infrastructure will be flexible and reconfigurable to accommodate evolving standards, applications and the end-user needs. 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 E^2R research project, its architectural framework and approach, as well as the E^2R II project ambitions (2006-2007).

1. INTRODUCTION

Within the End-to-End Reconfigurability (E^2R) [1], innovative research, development and proof of concept are sought in an end-to-end aspect, stretching from user device all the way up to Internet Protocol, and services, and in reconfigurability support, intrinsic functionalities such as management and control, download support, spectrum management, regulatory framework and business models. End-to-end reconfigurability systems will provide common platforms and associated execution environments for multiple air interfaces, protocols and applications, which will yield to scalable and reconfigurable infrastructure that optimise resource usage, increased network and equipment capability and versatility by software modifications. The users will benefit from these capabilities by reaching the required service at times and places when and where needed at affordable cost.

Launched within the 6th Framework Programme (FP6) [2] of the European Commission (EC), the End-to-End Reconfigurability (E^2R) project is undertaking a long-term 6-year lifetime with ultimate goals of research, design and proof of concept of reconfigurability and is articulated in three major phases:

- Phase 1 (E^2R I) (2004-05) is a definition phase identifying stumbling blocks, consolidating the heritage of former work, and further developing concepts and solutions. The brand-new concept of this first phase was to bring together some key independent research activities initiated in former EC 5th Framework Programme (FP5) and to assess the feasibility of an integrated system for the support and provision of reconfigurability,
- Phase 2 (E^2R II) (2006-07) is concentrating on most promising solutions identified in E^2R I and will assess any emerging new technologies, while in parallel evolving towards integrated framework,
- Phase 3 (2008-2009) will complete the proof of concept evolutionary environment by demonstrating that reconfigurability could be implemented. Future research themes will be prepared to help the European Research Area (ERA) to pursue his research within the 7th Framework Programme (FP7).

This project is including major key European players in the domain of Reconfigurability, Software Defined Radio (SDR) and Cognitive Radio (CR), who have an accurate understanding of the state-of-the-art from various projects and bodies. These previous initiatives of course motivated the E^2R project, but today's ambitions, especially after the first eighteen months, go further to the end-to-end aspect and reconfigurability support aiming at providing the seamless experience to the users, enabled by the end-to-end reconfigurability. Reconfigurable equipment and systems will provide much higher flexibility, scalability, configurability and interoperability than currently existing mobile communications systems. Reconfiguration will stretch over all OSI layers, on open platforms where the complete protocol stack will be subject to reconfiguration. To achieve the E^2R project ambitions, three major challenges were identified in E^2R I: (1) Transforming embedded flexibility into end-to-end reconfigurability, (2) Capturing the newly enabled functionalities of E^2R into valuable benefits, and (3) Finding right balance between integrated versus distributed approaches. These axes are driving the definition of an architecture and design of reconfigurable and flexible system concepts that enable seamless and transparent communication across these heterogeneous environments. An active

cooperation between end-users, operators, manufacturers, service providers and new comers is needed to firm up the definition of the most appropriate distribution of intelligence between reconfigurable terminals and networks. E²R is thus contributing to the realisation of the ambient space through which a modern society interacts and communicates with key capabilities of the radio eco-system and finally actively influence European industrial and economic competitiveness. This paper is presenting the E^2R architectural framework in Section 2. The E^2R I approach and E^2R II ambitions (2006-2007) are introduced in Section 3. Finally, in Section 4, a short summary concludes the paper.

2. E^2R ARCHITECTURAL FRAMEWORK

An important trend within the ambient space is the emergence of communication systems that are composed, to a significant degree, of dynamically configured distributed components, whereby optimised resources should be anticipated while keeping its complexity hidden. Additionally, in the past years, the wireless telecommunications sector has lead to the development of a wide range of technologies like 2G, 3G, WLAN, WMAN and DVB and its associated equipments. This represents valuable diversification of the radio eco-space that has already made a technology push towards multimode devices and produced significant investment into research of new technologies, services and business models adapted for collaborative heterogeneous radio systems.

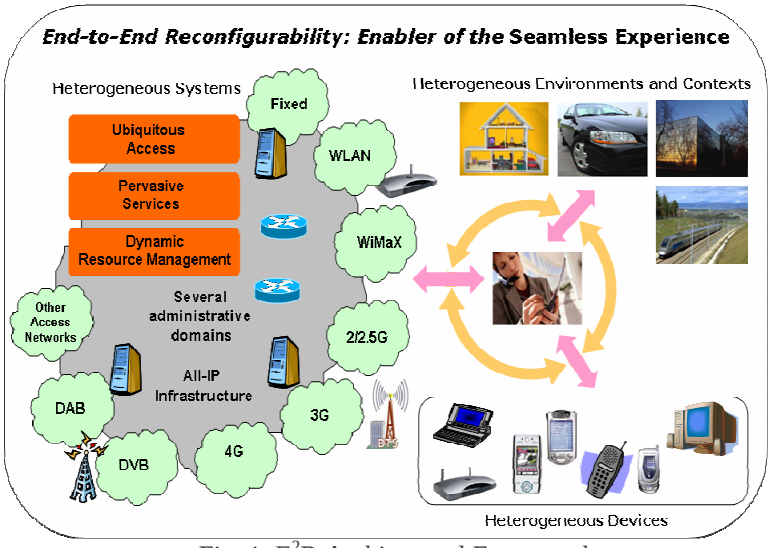

Fig. 1: E^2R Architectural Framework

The ultimate vision of E^2R is to reach all-IP fully integrated networks with reconfigurable equipment and associated discovery, control and management mechanisms. Within this ambient space, the users will benefit from end-to-end reconfigurability by reaching the required services, at affordable cost, in different heterogeneous contexts, using diverse equipments and through several technologies. The E^2R architectural framework, enabling the seamless experience, is depicted in Figure 1, where the users are considered to be at the centre of the future telecommunications environment, using heterogeneous devices (such as end-user mobiles, personal network equipments…), in heterogeneous environments and contexts (such as home, office, on the move…) and through heterogeneous systems (such as fixed, wireless local area networks, cellular and broadcast technologies…).

Within this overall architectural framework, all stakeholders will benefit from end-to-end reconfigurability: (1) Operators will benefit from a scalable and reconfigurable infrastructure that optimises resource usage, and by which new applications, services and technologies can be offered more efficiently. It will be possible for operators to maximize the Return on Investment (RoI) of legacy networks, while transitioning to IP-based core network in order to drive cost down. They will enjoy high RoI, improve networks Key Performance Indicators (KPIs), and reduce CAPEX (lower deployment costs) and OPEX (higher business volume and revenue), (2) Users will benefit from an integrated telecommunications environment offering variety of services and applications at affordable prices. They will be able to use reconfigurable equipments to access services when and where they need them, experiencing seamless availability and accessibility to desired services, (3) Service and application providers will benefit from the open flexible platforms and associated execution environment for deploying enhanced features and services in reduced time frames and product development cycles, (4) Manufacturers and vendors will be able to target wider markets by offering customized solutions. The development of “plug and play” technology will ease migration to new standards, future air interfaces, protocols and also to applications that are unknown as of today. Consequently, the time-to-market of a product will be significantly decreased and the customer support facilitated, (5) Regulators will consolidate a framework wherein the wireless environment should evolve. The concepts and technologies to facilitate a shift of the regulatory regime from the currently rather static scheme to a rule-based regulation framework that facilitates rapid regulatory adjustments when and where necessary. Global harmonization of the regulation approaches for spectrum usage and equipment reconfiguration is one important goal.

3. E²R PROJECT PHASE 1 APPROACH AND PHASE 2 AMBITIONS

In order to drive the E²R research work to success, the following technical approach was adopted over the whole duration of the Phase 1: (1) Capture compelling use cases, establish a model architecture of the E²R system and define an overall end-to-end reconfiguration framework, (2) Design and prove the concepts of technical solutions to implement reconfigurability in all the layers of an end-to-end wireless communications system, (3) Develop a flexible, modular and evolutionary proof of concept environment for validation purposes, and (4) Disseminate, contribute to related standardisation bodies, organize training sessions and ensure worldwide recognition of the E²R results.

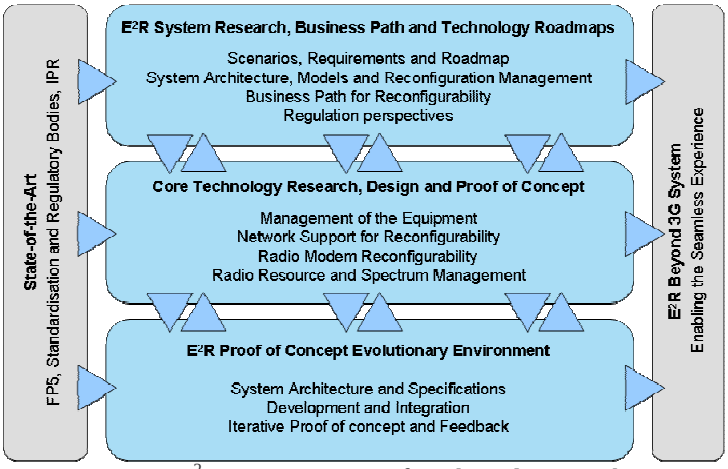

Fig. 2: E²R I Organisation of Technical Research

The organisation of technical research adopted by the E²R project is depicted in Figure 2 wherein three main components are introduced. The "E²R System Research, Business Path and Technology Roadmaps" component is focusing towards compelling scenarios and stakeholders requirements of the radio eco-system. The "Core Technology Research, Design and Proof of Concept" component encompasses the technologies needed to transform embedded flexibility into end-to-end reconfigurability, while finding the right balance between integrated versus distributed approaches. Finally, the "E²R Proof of Concept Evolutionary Environment" component is enabling the validation of the charter of research as a whole, thus establishing the proof of concept of the system within the radio eco-space.

Building on the successful development of the project, the next steps of E²R will demonstrate technologies that enable a true seamless experience based on reconfigurable heterogeneous systems. Next steps will pursue research in the most promising directions towards removing walls (current technical and regulatory limitations) and building bridges (technical) in order to facilitate the development of the true end-to-end connectivity. As already expressed, the charter of E²R II 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 users, applications and service providers, operators, manufacturers, and regulators in the context of heterogeneous mobile radio systems.

The approach adopted by the consortium in E²R II proposal, submitted to EU Commission, is depicted in Figure 3. The E²R II is structured around two main research components, building on E²R I and other FP6 projects and initiatives, and targeting the E²R Beyond 3G System enabling the seamless experience to the users:

- "E²R II Research Challenges" will focus on progressing the challenges that the E²R project is addressing, such as enabling the sustainable business development of reconfigurable systems, the end-to-end reconfiguration management and control architectural framework, the efficiency enhancement of radio resource and spectrum, and the end-to-end seamless connectivity as well as building the European reference prototyping environment for end-to-end reconfigurable systems and solutions.
- "E²R II Research Domain Skills" will bring the expertise within the cognitive networks, reconfigurable equipment and proof-of-concept research domains, serving the different challenges, and targeting standardisation and regulatory contributions.

As initially planned, synchronisation points with time intervals (during the 6-year lifetime) between the different components will establish the convergence to a set of common functionalities to be deployed on the E²R Beyond 3G System. The adopted approach for E²R II is emphasising the synchronisations between the different research areas of the project. At the beginning of the E²R II project, both research components of the proposed approach will assimilate the technical information in the different areas in order to define inter-dependencies between the constituent technical areas within the radio eco-space. In addition, it will help define the yet non-researched technical areas, which are appropriate to the development of the E²R charter. The E²R II project will contribute to the specification and implementation of reconfiguration management functionality devised to operate end-to-end and to account for multiple actors, diverse Radio Access Technologies (RAT), equipment capabilities, and network infrastructures, driven by service-specific and resource-aware strategies. This E²R II approach results in a natural cycle of continuous technology

watch and short-medium-long term conceptual research while guaranteeing the development and delivery of enabling technologies realising the Beyond 3G Seamless Experience. In order to fully satisfy the objectives, the project proposal structure of E^2R II has been devised as depicted in Figure 4, based on a clear matricial organisation of the E^2R II in challenges ("horizontal WPs") and domains skills ("verticals WPs). The intention in building the new structure of E^2R II was to develop a tighter integration of the various research tracks (WPs) and a stronger interoperation between the different technical and technological facilitators under investigation in E^2R.

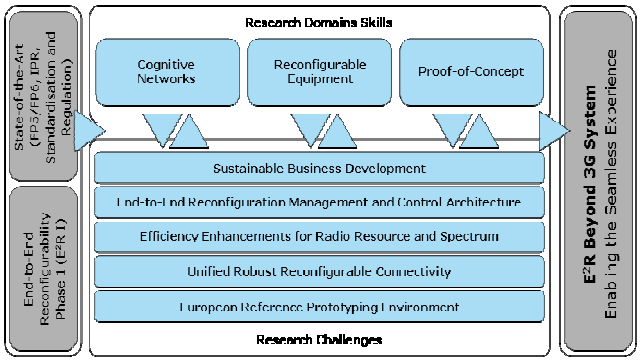

Fig. 3: E²R II Research Components

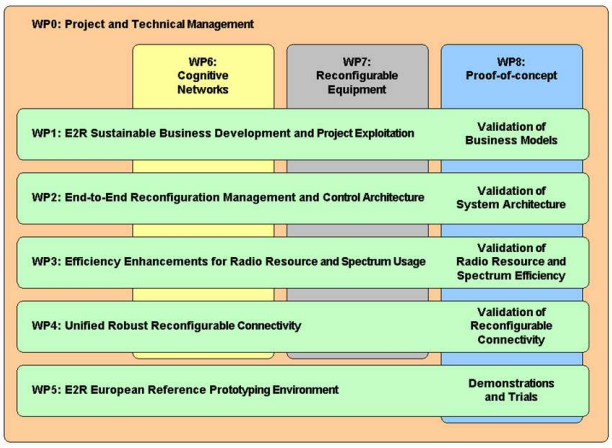

Fig. 4: E²R II Project Structure

The main challenges of E^2R II will be to develop and demonstrate solutions for interoperability, scalability and flexibility, enabling efficient support of ubiquitous access, pervasive services and dynamic resources management in the radio environment of the future. These research areas will drive the definition of system reference models and the distributed demonstration of resource management across multiple wireless/wireline access networks and multiple operators, with support of legacy architectures, thereby enabling seamless and transparent communication across these heterogeneous environments.

4. CONCLUSIONS

This paper has presented the E^2R research project, partly funded by the European Commission, and the approach adopted in Phase 1, as well as the E^2R II ambitions (2006-2007). The E^2R project aims at bringing full benefits of the radio eco-space diversity making heterogeneous environments transparent, flexible and intelligent. The ultimate vision of the E^2R research is to reach an all-IP fully integrated networks with reconfigurable equipment and associated discovery, control and management mechanisms. Therefore, research in the end-to-end aspect (stretching from user device all the way up to internet protocol and services) and in reconfigurability support (intrinsic functionalities such as management and control, download support, spectrum, regulatory issues and business models) is required to realize this vision.

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 equipment 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.

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