END-TO-END RECONFIGURABILITY – MANAGEMENT AND CONTROL OF ADAPTIVE COMMUNICATION SYSTEMS

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ABSTRACT

The End-to-End Reconfigurability (E^2R I & II) program develops concepts and solutions to enable, manage and control end-to-end connectivity in B3G heterogeneous environment (cellular, 802.xx, broadcast…). The key objective of the E^2R II project is to devise, develop, trial and showcase architectural design of reconfigurable devices and supporting system functions to offer an extensive set of operational choices to the users, application and service providers, operators, manufacturers and regulators in the context of heterogeneous systems. This paper discusses the E^2R II research framework and focuses on some of the latest concepts and solutions developed by the consortium.

1. INTRODUCTION

Building on the successful developments of the first phase, E^2R II is demonstrating and validating technologies that enable a true seamless experience based on reconfigurable heterogeneous systems. The project is pursuing research into the most promising directions towards removing walls (current technical and regulatory limitations) and building bridges (technical) in order to facilitate the vision of true end-to-end connectivity.

The main challenges of E^2R II are 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:

- Design generic system mechanisms that implement seamless experience management, these mechanisms build on, and are compatible with, legacy system management solutions in a multi-access situation,
- Evolve the E^2R I architecture to implement the seamless experience management structure that spans across domains, thanks to open, standardised protocols for management in multi-access/multi-owner situation,
- Define global access/resource management structure extending the E^2R architecture, building on, and compatible with legacy solutions,
- Evolve the equipment management methods to include them as part of E^2R architecture building on, and compatible with, legacy management solutions,
- Introduce and further relevant autonomic computing approaches which are used to manage IT networks,
- Develop cognition-based mechanisms facilitating efficient access to resources in multi-owner situations,
- Enable relevant inter-layer communication in a multi-access/multi-owner situation,
- Implement partitioning framework for applications/ service provisioning and connectivity provisioning,
- Contribute to regulatory and standardisation bodies for the development of globally harmonised solutions for reconfigurable terminal and networks,
- Facilitate active cooperation between end-users, operators, service providers and “new comers”, needed to firm up the definition of the most appropriate distribution of intelligence between reconfigurable terminals and networks.

The subsequent sections of this paper present an overview of the E^2R II research project achievements as well as some of the technical areas that are currently tackled.

2. E^2R II PROJECT EXPECTED IMPACT

Having the aim to support making Europe a first choice for investments into ICT, E^2R II impact on standards and its input to shape future regulation will be increased. The advantages for industry and users can be captured as follows:

- Efficient, advanced and flexible end-user service provision. The reconfigurability management of the network and systems will also be serving the optimal provision of end-user services and applications. The aspect of end-to-end reconfigurability encompasses tailoring of application and service provision implementing user preferences and profiles, while considering network/terminal capabilities, configuration and equipment profiles, as well as service / charging / security profiles and related context, thus supporting and employing the principles of context aware and ambient intelligent systems,
- Efficient spectrum, radio and equipment resources utilisation. With close collaboration with the

regulations authorities, enabling technologies for flexible spectrum resources and the associated usage, equipment circulation and security issues will be devised. The outcome of E^{2}R II input to the regulatory discussions is intended to lead to a simplified regulatory framework which allows the flexible assignment and use of spectrum facilitated through techniques that implement an optimised resource usage. The aim to facilitate simpler and more market aware flexible spectrum management will be exploited through the use of equipment and systems capable to reconfigure and to be operable in situations where private users to access portions of unlicensed bandwidth,

- Reduced cost to upgrade fielded systems. Technologies investigated and developed in E^{2}R II will help making equipment upgradeable through software downloads (e.g. over the air in case of mobile devices of end-users), meaning that both small changes to system parameters, as well as complete exchange of the communication standards implemented can be performed. This will improve both, the economics of expensive infrastructure systems as well as the efficiency of resource usage, as systems may be configured to serve the actual load situation in an optimised manner,
- Multi-standard platforms. As radio standard implementations of equipment will be combinations of hard and software, it will be possible to dynamically share single hardware platforms between multiple radio implementations. This will facilitate that channel resources may be shifted among different communications standards as reaction to actual load shifts. Hence, the cost of the infrastructure to support a mixture of legacy and newly deployed fixed-standard radio equipment can be reduced significantly,
- Better support for customised solutions. Developers or vendors will be able to modify the communications standards of devices without having to invest in a new hardware design. Users who need relatively small volumes of devices, for whom the cost of custom hardware is prohibitive, will gain the ability to improve their operations with devices optimised and customised to their special needs,
- Reduced standards risk. Operators deploying expensive infrastructure (including base stations, access points or gateways…) or large numbers of mobile devices will be able to do so without locking into the communications standard that will initially be used. This will help the operator to avert potential changes in standards and will also provide them with the possibility to react to changes in user requirements or user (market) behaviour.

3. E^{2}R II RESEARCH FRAMEWORK

The E^{2}R II project is focusing on the following study axes (Fig. 1): Business development and project exploitation, end-to-end reconfiguration management and control architecture, efficiency enhancements for radio resource and spectrum, unified robust reconfigurable connectivity and European reference prototyping environment. This effort is organized in a matrix structure: Five *horizontal* Work Packages (WPs) organize specific technical contributions, three *vertical* WPs coordinate the effort on cognitive networks, reconfigurable equipment and proof-of-concept studies.

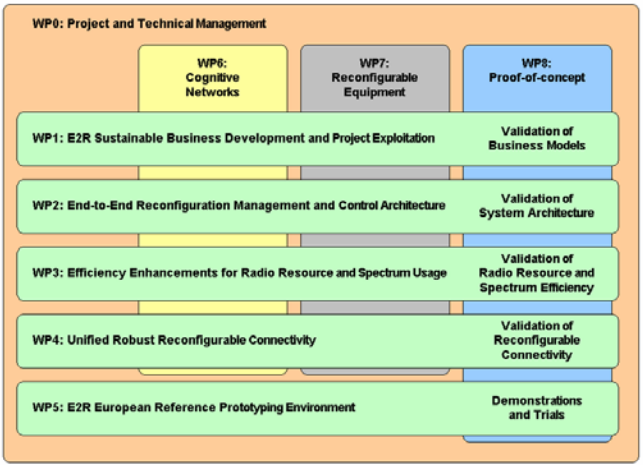

Fig. 1: E²R II Research Framework

The high-level charters for the eight WPs are the following:

- WP1: "E^{2}R Sustainable Business Development and Project Exploitation" develops and analyses business models and roadmaps for end-to-end reconfigurable systems. WP1 also builds coordinated standardization and regulation plans and clarifies the overall E^{2}R II contributions,
- WP2: "End-to-End Reconfiguration Management and Control Architecture" aims at devising end-to-end reconfiguration management and control architecture together with optimal split of intelligence and functionalities between cognitive network elements and reconfigurable end-user equipment. The developed protocols and mechanisms exploit emerging concepts of autonomous systems,
- WP3: "Efficiency Enhancements for Radio Resource and Spectrum" aims at further enabling and broadening the range of mechanisms available to increase the efficiency of radio resource usage,
- WP4: "Unified Robust Reconfigurable Connectivity" enables robust (stable, secure, reliable) end-to-end connectivity in a multi-access/multi-owner environment. Trade-offs amongst power efficiency, timing constraints and resource sharing are

determined. Validated reconfiguration processes are prepared for standardisation,

- WP5: "E²R European Reference Prototyping Environment" builds a reference prototyping environment for end-to-end reconfigurable systems and solutions, thus enabling the validation of the reconfigurability vision developed in E²R II,
- WP6: "Cognitive Networks" aims at establishing a common framework in the European R&D area of cognitive radios and networks, contributing to their definition and future role,
- WP7: "Reconfigurable Equipment" aims at developing a detailed understanding about how reconfigurable equipment, both in the network and in the terminal, can be used in a commercially viable end to end reconfigurable system,
- WP8: "Proof-of-concept" is targeting the validation of business models, system architecture, mechanisms for radio resource and spectrum efficiency, and platform for dynamic and robust reconfigurable connectivity.

4. E²R II RESEARCH OUTCOMES HIGHLIGHTS

Having the aim to support making Europe a first choice E²R II is building on the successful approach of E²R I, developing in parallel the three main segments of the technical, business and regulatory research. The ten golden nuggets from E²R I were defined (March 06) as:

- Unified Business Model (UBM),
- Responsibility Chain Concept,
- R&TTE Directive Extension for Reconfigurable Equipment,
- End-to-End Reconfigurability System Architecture (SA),
- Reconfiguration Management Plane (RMP),
- Network Support Architecture for Reconfiguration,
- Functional Architecture (FA) for Resource Efficiency,
- Cognitive Pilot Channel (CPC),
- Equipment Management and Control (EMC) Architecture,
- Functional Description Language (FDL) for Physical Layer Processing.

This section is highlighting some key E²R II developments and their expected impacts.

E²R II Unified Business Model (UBM)

Developing the research on business models initiated in E²R I, the project has defined the version 2.0 of the Unified Business Model (UBM) for B3G Ecosystem (Fig. 2). This model is currently used to make real-world instantiations which reflect the provision of specific services making use of reconfigurability concepts.

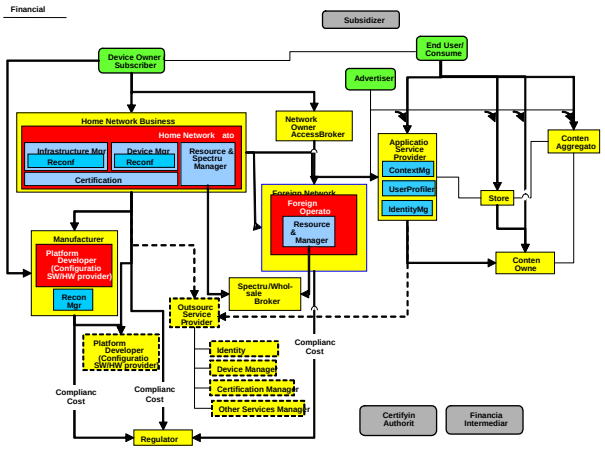

Fig. 2: E²R II Unified Business Model (UBM)

E²R II System Architecture

E²R II envisages autonomic communication as the paradigm of next-generation mobile systems that exploit SDR and CR, and consist of terminal equipment and network elements with autonomic decision-making and self-management behaviour, whereas being capable of enriching their knowledge and generating dynamic policy rules based on contextual information.

E²R II efforts on end-to-end system architecture modelling capture the challenge of autonomic communication. Key thematic areas are surveyed such as user profile definition and handling, ontologies and context models, enabling technologies for device management, self-configuration and self–management, and autonomic decision-making. E²R II project develops a unified scenario involving autonomously reconfigurable terminal equipment and network elements. The purpose of this global scenario is to encompass all aforementioned areas of E²R II reconfiguration research within a single storyline, thereby highlighting important issues which must be addressed. The work builds on this unified scenario through detailing its important use-cases along the aforementioned research axes, while adhering to the autonomics rationale. Required system capabilities are derived from use-case diagrams, leading to the definition of a functional model that comprises the end-to-end system architecture. As one example, a "policy management" use-case is defined and functionalities are mapped to specific modules in the evolved E²R II Reconfiguration Management Plane (RMP).

The RMP model views the reconfigurable element as an autonomous entity, offering cross-layer control and management reconfiguration capabilities. The RMP consists of the Autonomic Decision-Making and Reconfiguration Management (ADM-RM) module, the Cognitive Service Provision (CSP) module, the Software Download

Management (SDM) module, the Self-Configuration and Management (SC-M) module, and the Context Management (CtxM) module (Fig. 3) [4].

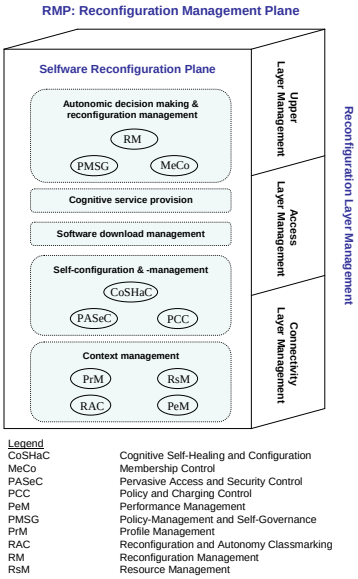

Fig. 3: The Reconfiguration Management Plane Model for Autonomously Reconfigurable Elements.

The ADM-RM module produces and evaluates dynamic policy rules based mainly on business goals, and exploits self-knowledge and contextual information in order to formalise the autonomic behaviour of the reconfigurable equipment or network element. The CSP module discovers the reconfiguration capabilities that can be offered by candidate networks, and supports content and service adaptation. The SDM module administers the software download process, whereas the SC-M module is capable of improving the use of the reconfigurable entity's resources as well as of optimising the overall operational performance through self-healing and self-configuration procedures. In addition, it accommodates security, pricing, and charging facilities. Finally, the CtxM module defines, retrieves, updates, and stores profile information, manages generic resources that are not tailored to specific protocol layers, defines additional labels that characterise the reconfiguration and autonomy capabilities of the entity, and generates performance measures both for the optimisation of the reconfiguration process and for the upgrade of the level of autonomy of the entity.

E²R II Radio Resource Optimization and Cognitive Pilot Channel (CPC)

E²R II is building on E²R I in further developing and integrating the different technical approaches for spectrum and radio efficiency increasing technologies and methods into a common framework defined as Functional Architecture (FA). Mechanisms and protocols are developed for Cognitive RANs in single operator situations as well as mechanisms and algorithms for allocation and trading of radio resources in multi-operator situations (Fig. 4). E²R is also developing concepts and solutions for a Cognitive Pilot Channel (CPC), encompassing both in-band/out-band and downlink/uplink functionalities. The initial work on the CPC is building on bi-directional information flow between network and end-user devices in order to (1) ease and fasten decision on the network side, thanks to information available locally on user equipment side and (2) enable the distributed decision-making between network and terminals, relying on information coming centrally from the network. This will make converge both Cognitive Radio and Networks.

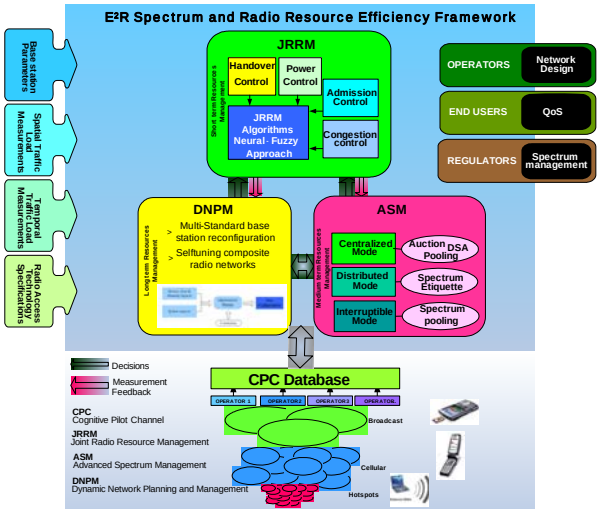

Fig. 4: E²R II Spectrum and Radio Resource Efficiency Framework

E²R II Prototyping Environment and Proof-of-Concept

E²R II attributes high importance to validation activities. In particular, the objectives of the validation work can be summarized in the following:

- To define validation criteria, both qualitative and quantitative, for the work on business models, system architecture, enhanced radio resource and spectrum efficiency mechanisms, and platform for dynamic and robust reconfigurable connectivity,
- To refine scenarios defined in E²R I that will ensure the realisation of comprehensive validation studies, for the components of the horizontal WPs, which will be demonstrated and validated through the Reference Prototyping Environment (RPE),
- To realise the integration of the selected parts that will be demonstrated and validated through the E²R reference prototyping environment. This will involve work on business models, system architecture, mechanisms for radio resource and spectrum

efficiency, and the platform for dynamic and robust reconfigurable connectivity,

- To realise the local prototyping activities and trials, according to the specified test cases, and to assess the degree of compliance with respect to the validation criteria,
- To provide feedbacks to the horizontal WPs in term of global coherency of the developed functionalities and mechanisms.

Regarding the approach that will be followed to reach these objectives, it is anticipated that after the different criteria have been identified and the demonstration scenarios have been refined, the integration of the selected parts that will be demonstrated will follow. This will be performed through the RPE. Then, in the end, the prototyping activities and trials will be implemented and feedback will be collected. The areas of work that the demonstrations address are (1) RPE (on which the several parts will be integrated), (2) Platform for dynamic and robust reconfigurable connectivity, (3) Enhanced radio resource and spectrum efficiency schemes, (4) System architecture and (5) Business models. The framework that reflects the way these areas form part of the validation activities, is depicted in Fig. 6.

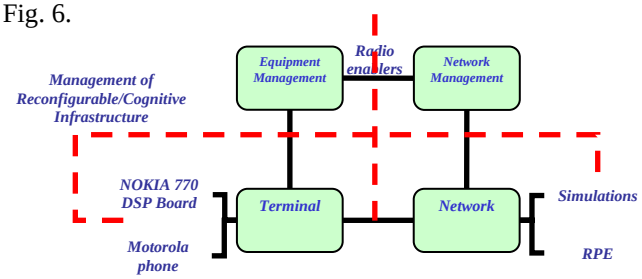

Fig. 6: Overall View of Validation Approach

Individual demonstrators, a first one for reconfiguration support for terminals (reconfigurable equipment) and a second one for the network support for the reconfiguration process, will be integrated upon the reference prototyping environment. In general, the validation work that relies on demonstrations and trials, will be complemented through analytical studies (i.e. development of analytical tools) and system simulations (which will be conducted within local / specific demonstrators). Finally, it is one E²R II goals to realise the demonstrations and trials, according to the scenarios and test cases, which, as previously mentioned, will specify the features for each demonstration activity, so as to obtain feedback and evidence on the project achievements. The compliance with respect to the criteria will be assessed. Results need to be collected and used for fine-tuning the E²R components, as well as for dissemination. In this context, E²R II held a successful demonstration in IST Summit 06 in Mykonos (see Fig. 7), where different scenarios were carefully tested and demonstrated on custom-developed simulation platforms. Feedback was highly positive and will set the scene for further developments and demonstrations.

Fig. 7: Demonstration in IST Summit 06

6. CONCLUSIONS

This paper has presented the ambitions of the E²R II research project, that is partly funded by the European Commission, and several fields of research currently investigated. The E²R II project aims at bringing full benefits of the radio eco-space diversity making heterogeneous environments transparent, flexible and intelligent. The ultimate vision of the E²R research is to reach an all-IP fully integrated network with reconfigurable equipment and associated discovery, control and management mechanisms.

7. ACKNOWLEDGMENTS

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