FP7 E³ PROJECT: TECHNICAL, BUSINESS, STANDARDIZATION AND REGULATORY PERSPECTIVES

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ABSTRACT

E³ [1] is aiming at integrating cognitive wireless systems in the Beyond 3G (B3G) world, evolving current and future heterogeneous wireless system infrastructures into an integrated, scalable and efficiently managed B3G cognitive system framework from a technical, regulatory, standardization and business perspective.

A detailed description of the E³ project was presented during the 2007 SDR Forum Technical Conference [2]. This paper provides an update on technical, business, standardization and regulatory perspectives describing the approach and first results of the project.

1. INTRODUCTION

The key objective of the E³ project is to design, develop, prototype and showcase solutions to guarantee interoperability, flexibility and scalability between existing legacy and future wireless systems, manage the overall system complexity, and ensure convergence across access technologies, business domains, regulatory domains and geographical regions.

There are four main targets within E³: (1) To increase system management efficiency for network operation and (re)configuration building on cognitive system and distributed self-organization principles. (2) To define means to increase the efficiency of wireless system operations, in particular by optimally exploiting the full diversity of the heterogeneous radio eco-space. (3) To enable a gradual, non-disruptive evolution of existing wireless networks in accordance to user requirements. (4) To design a Cognitive Radio System exploiting the capabilities of reconfigurable networks and self-adaptation to a dynamically changing environment. This paper highlights some of the main challenges E³ is addressing and introduces the chosen technical approach that shall enable introduction of Cognitive Radio Networks in a not so far future.

Figure 1 depicts the main challenges of the project:

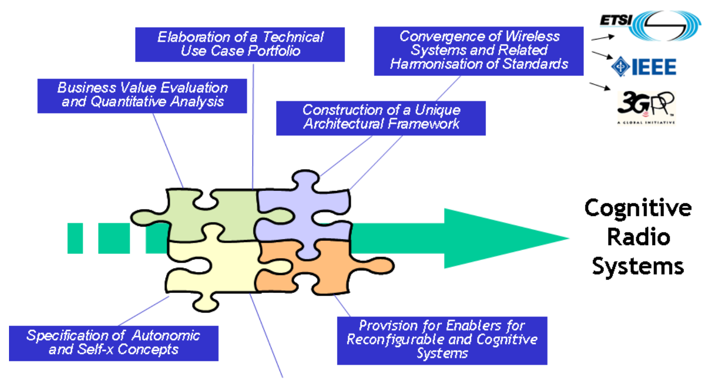

Figure 1: Main Challenges addressed by E³

2. BUSINESS RESEARCH

Goal of the business research work is twofold: First, to detect and analyze markets and business opportunities potential for Cognitive Radio Systems, and then to provide value propositions and their evaluation for these Cognitive Radio Systems, including a qualitative and a quantitative evaluation of financial transactions among all stakeholders and their roles. The identification of market opportunities for cognitive systems is based on the Unified Business Model (UBM), and the corresponding analysis uses the Business System Architecture Process (BSAP) methodology [3].

Through dedicated interviews of manufacturers and operators, the perception of these key stakeholders is used to develop the value propositions for selected use cases, and more generally to collect their feedbacks on the E³ technical work and standardization and regulation options.
With a nearly similar methodological approach, the perception of users about enriched mobile communications

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is surveyed by focus groups addressing early adopters, in addition to quantitative survey methodology in several EU countries.

In terms of business models, a model for network and resource optimization is developed with six identified key categories of variables (territory, market, services, technology and networks, capital and operational expenditures, and spectrum) that takes care of the cost aspects. A specific focus is made on the case of the Cognitive Pilot Channel (CPC) for which possible revenue sharing models are studied [4].

The identification of market opportunities for cognitive systems fully exploits the Unified Business Model (UBM) set of actors and roles defined within the eco-system. Based on the E[3] scenarios and technical use cases, the mapping to the UBM (actor, role, UBM role) is made together with a series of value propositions for different use cases or families of use cases (Self-optimization in heterogeneous networks, Self-optimization in Single-RAT networks, Self-maintenance/self-healing, Self-(re-)configuration). A detailed analysis for Network supervision, spectral resources optimization, and supply of enriched mobile communication services can be found in [5].

3. SYSTEM ARCHITECTURE

E³ considers new upcoming functionalities to improve the efficiency of the existing world of composite wireless networks.

Besides the mapping of these new functionalities into existing networks, also a differentiation is made between single- and multi- Radio Access Technology (RAT) networks, as well as between single and multiple operator environments. Figure 2 shows the functionalities and this differentiation.

An approach on architectural development of Composite Wireless Networks and Cognitive Radio Systems has been defined. Starting from a schematic figure showing the current situation, additional modules/entities for the implementation of the functionalities described above are introduced. Also, the expected time for introduction of new functionalities is taken into account.

Further, the general direction of the development of management functionalities in future wireless systems is considered. The way leads from traditional management via self-organization (being context-aware, following policies, and profiles) to self-learning management that orients itself on pre-defined targets.

Concerning the assessment framework, an architecture extension has been depicted that allows for assessing cognitive radio systems. This includes the assessment of self-learning system capabilities. It has been identified that assessment has to be taken into account during all the system life cycle - from the system specification until its deployment.

The architecture takes into account the related work within the IEEE P1900.4 and ETSI RRS standardization. Special focus is given on the functions of the architecture that are used to derive radio resource selection policies, which will guide the terminals' operation within the complex radio environment [9].

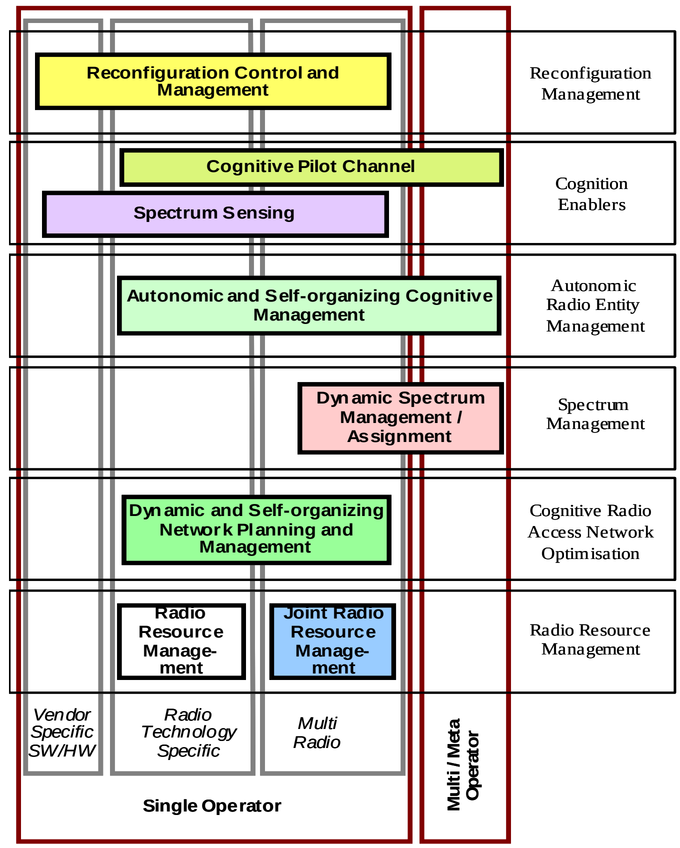

Figure 2: Architecture of Functional Blocks and Areas

4. TECHNICAL USE CASE PORTFOLIO

Within E³ a set of categories of technical use cases has been defined along with their potential implementation time frame.

Figure 3 shows these categories and the expected time ranges for their implementation. Scenarios as illustration of the technical work are defined and related to self-x, flexible spectrum management and Cognitive Radio (CR) terminals (incl. CPC aspects). Especially, an illustrating multi-media scenario has been defined that will be realized in the ongoing project phase.

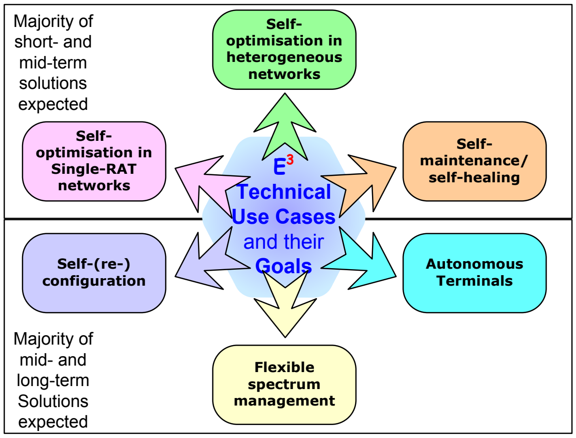

Figure 3: Categories of Technical Use Cases

5. COGNITIVE PILOT CHANNEL FUNCTIONALITIES

The proposal to introduce a Cognitive Pilot Channel (CPC) into heterogeneous wireless systems is one of the main outcomes of the E^{2}R II and it is also a topic of E³ project. The main goal of the CPC is to support an efficient discovery of the available radio accesses and reconfiguration management in heterogeneous wireless environment between network and user terminals. In its system studies, E³ is addressing several aspects related to the CPC definition and functionalities, such as the localization issues due to the CPC usage, the CPC mesh dimension evaluation and its possible optimization, the CPC databases, the related coherent information and the CPC parameters.

The CPC concept formulated in E^{2}R II can support a number of functionalities, such as enabling switch-on in flexible spectrum scenarios, provision of relevant information for secondary usage of spectrum (e.g. Dynamic Spectrum Access), provision of resource management policies, etc. as reflected in Figure 4.

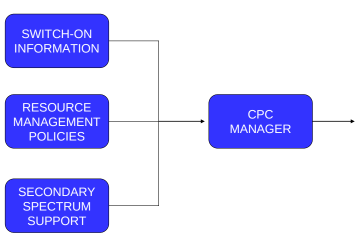

Figure 4: CPC's Functionalities.

In addition to the work done in E^{2}R II, the E³ project is aiming to enhance the already defined CPC functionalities as well as to introduce and study new functionalities that could be useful to increase the end-to-end efficiency inside an heterogeneous system.

The main CPC functionalities under study could be summarized as follow:

- Provision of knowledge of available radio networks at a certain location (e.g. Operator, RAT, frequency). When turned on, the mobile terminal is not aware of which are the available RATs in that geographic area where it is located, or which frequency ranges the RATs existing in that specific geographic area exploit (especially in case of DSM-enabled context). Terminal in such situation could retrieve the useful information through CPC, avoiding excessive latencies. Different operating mode have been investigated for the CPC such as the Broadcast and the On-demand solutions,
- RRM policies/constraints provision. In the context of Distributed Decision Making, CPC could be of help for the selection of the preferred radio links among a plurality of available alternatives according to resource selection constraints imposed by the network through the CPC. Another example could be the vertical HO procedure, where the useful information to perform the RAT changes are provided by the CPC,
- Radio context information and performance information. CPC could transport also information related to the radio context in which the terminal is located,
- Reconfiguration and Software Download support. Reconfigurable terminals could be triggered by CPC for a reconfiguration and also the relevant software could be downloaded through the CPC itself.

Besides their utility in a heterogeneous system, the functionalities reported above, involve by consequences a wide range of related issues. From an implementation point of view, different solution for the CPC could be developed such as the Out-Band and the In-Band alternatives. Furthermore, also management aspects of the CPC are relevant (e.g. the need of a database to manage the information sent by CPC). Finally, the performance evaluation of the adopted solutions (e.g. in terms of delays to provide to a terminal the information) are an important point to be considered. All these aspects will be investigated in the E³ activities.

6. COLLABORATIVE COGNITIVE RADIO RESOURCE MANAGEMENT (RRM)

Aim of enhanced radio resource management (RRM) for next generation mobile and wireless systems which will consist of heterogeneous networks is twofold: An efficient use of radio resources available to the co-existing networks shall be ensured and proper mechanisms enabling the radio access networks to meet radio resource related requirements in a self-organized way shall be provided. To meet these goals the solution has to consider enhanced support for end-to-end QoS, efficient transmission of higher layer information, and assistance for load sharing and policy management across different Radio Access Technologies. Deployment of RRM includes processes like networks context sensing, profile provisioning (related to both network elements and terminals), policy generating, decision making, optimization, etc. Also machine learning mechanisms to adaptively or proactively predict resource management solutions from former experience and/or for an expected system behavior is in scope of the foreseen activity.

Based on corresponding use cases mentioned in the section above the work performed by E³ will analyze, evaluate, and enhance by means of system level simulations potential solutions.

Solutions developed within E³ will optimize the use of spectrum and radio resources by means of cognitive network mechanisms and collaborative decision-making between network elements and user terminals. Self-organized intelligent cooperation may cover different network levels, RATs and administrative domains. This cooperation shall ensure efficient and flexible admission of calls and sessions, distribution of traffic, power and other radio parameters, thereby aiming at an optimized usage of radio resources and maximized system capacity in the heterogeneous networks.

The underlying mechanisms include e.g. genetic algorithms, reinforcement learning, game theory, pattern matching, and context based situation generation, etc. Both genetic algorithm and reinforcement learning [7] can solve the complex problems through iterative method and make the decision making of optimization issues faster and less complex. The target of pattern matching algorithm is to find the closest pattern for the new context and retrieve its solution in order to be implemented. Game theory can be used in spectrum management to deal with cooperative and competitive relationship among operators, especially in the economic aspect of spectrum resource. Context based situation generation can distribute available context information to interested parties. An algorithm for the Radio Resource optimization has been developed [8].

7. SELF-ORGANIZATION

The self-organization paradigm is considered along its different manifestations addressed as ‘Self-X’. Research and standardization activities in this field include initial support of primary self-capabilities, such as the self-configuration and -optimization on radio networks dealing both with the user device and the infrastructure equipment side. As proposed by Next Generation Mobile Network (NGMN) initiative [11], the Self-X approach is already introduced by 3GPP with SON (Self-Organizing Network) principles in Release 8 for LTE (Long Term Evolution) [12]. E³ will design and develop algorithms addressing the observations of the cognition cycle and most importantly, the decision part of the functionality. In this context, E³ will further elaborate this framework by exploiting both more advanced autonomic capabilities on the terminal side and automatic operation of the radio network, such as self-planning, self-managing and self-healing and investigate required interfaces between end devices and network infrastructure equipment as well as control entities within a cognitive environment.

To enable a flexible adaptation of the radio access network to variable demands in terms of changing traffic volume and service characteristics is another goal of SON. The variability of the request for connectivity is reflected by e.g. diurnal variations, irregularity of the users mobility patterns, local and regional environments, and customer profiles.

Further objective of network self-organization includes automatic operational support via monitoring and control without enhancing network load and failure probability. Thus the same information required by the system to perform wanted activities shall be used for automatic provisioning of KPIs (Key Performance Indicators) for the network operator, whereas the additional signaling amount shall be more than compensated by the expected gain in unnecessary corrective actions.

SON functionalities shall also enable a reduction of user or terminal need for interaction replaced by a network initiated and evaluated decision on how to provide always the best connectivity to a dedicated user with service in the context of the whole system.

The study of Self-x techniques has continued with a selection of a use case and analysis of the 2G-3G scenario for the reconfigurable Base Transceiver Station (BTS) algorithm performances evaluation has taken place. The research on the utility based centralized self-configuration algorithm for network element self-reconfiguration and self-management is ongoing. Preliminary simulation results show an improvement of the overall performance of the system in terms of blocking probability and QoS satisfaction degree.

One focus for the Self-X functionality of self organizing networks (SON) is put on single radio access technology. In that context, the Self-X management tasks have been identified on the basis of the E³ use cases. An approach for a first top level mapping of SON functional entities on the evolved cellular radio architecture was discussed.

A decomposition of the cognitive functions for cognitive composite wireless networks into a schematic, top level functional architecture has been worked out. Mutual dependencies between JRRM, Dynamic Spectrum Allocation (DSA), Self-X and related functions have been analyzed, mutual interactions have been defined, and requirements for the optimization processes deduced.

As a key point for radio resource optimization in a distributed decision making approach, relevant network state information has been identified. Meaningful radio resource selection policies have been derived allowing inclusion of network preferences and, on a weight based metric, mobile terminal preferences.

Assessment is required to guarantee consistency, safety, purposefulness, security, and efficiency of the operation. For the purposes of behavior assessment it is useful to consider actions of policy-based self-management of network elements as instances of model-driven decision processes [10].

8. AUTONOMOUS COGNITIVE RADIO FUNCTIONALITIES

Another important research direction of E^3 is targeting on autonomous functionalities and algorithms in cognitive radio context. The motivation and need for utilizing such functionalities in heterogeneous wireless environments, implied by the cognitive radio context, stems from various, diverse reasons. These include e.g. the flexibility, scalability, and ease of adaptation that the autonomous algorithms can provide. They can also significantly reduce the complexity and latency of various system control functions in heterogeneous wireless environments when comparing to centralized solutions, and provide in built fault-tolerance and robustness against malfunctioning of part of system components.

The considered technical scenarios are the following: i) spectrum sharing and opportunistic spectrum access, ii) autonomic exploitation of operator and RAT selection, iii) self-* features for autonomous elements, and iv) cognitive device management. These scenarios provide a multifaceted view on the possibilities and challenges of autonomous functionalities.

As a given example, scenario ii.) is depicted in Figure 5. This scenario considers the deployment of a variety of RANs (Radio Access Networks) of different nature (e.g. legacy R99/R5/R6 UTRAN, LTE, IEEE 802.X) and with flexible spectrum assignment capabilities. Different operators can be available in different areas of the network. Secondary network's infrastructure, exploiting unused spectrum in space and time dimensions, may also be deployed in the scenario.

The main features characterising the scenarios are:

- Transmitters may be from different operators, use different RATs and different frequency bands at different times,
- Primary network exploits DSA (Dynamic Spectrum Assignment), i.e. frequencies assigned to different cells may vary along time,
- Secondary network operates on an opportunistic access basis. Exploitable bands can be those unused by primary network (e.g. thanks to efficient DSA) or available from other sources (e.g. broadcaster).

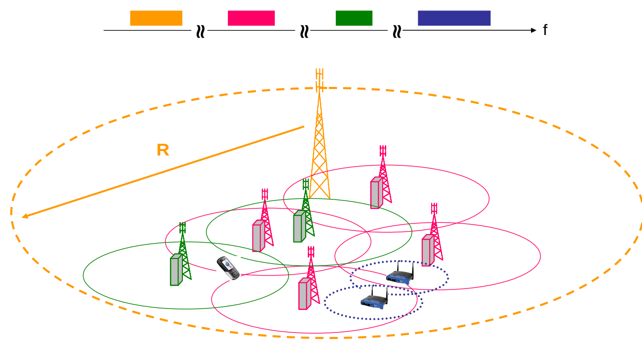

Figure 5: Heterogeneous Deployment with Flexible Spectrum Assignment

It is assumed that actual frequency assignment in both primary and secondary networks (i.e. which frequencies are available in each cell) is decided from network side (e.g. at the base stations), and then mobile devices will decide autonomously the specific RAT/frequency that they will use among the available ones. In turn, for a given cell, mobile devices are aware of actual operating frequency by any means (e.g. through CPC).

In this scenario, mobile devices should take autonomic decisions on the most suitable combination [Operator, RAT, Cell] to support specific services, based on current context information and possible future context evolution.

From these scenarios and related use cases required autonomous functionalities can be derived. Three groups of functionalities have been identified i) functionalities for creating awareness, ii) functionalities for autonomous, distributed control, and iii) functionalities for awareness signalling. The first group looks at means for generating the information based on which the system nodes can make decisions autonomous manner. The second group deals with the actual autonomous algorithms for various tasks and means. The third group focuses on methods how the information, which the nodes are utilizing for autonomous decision making, can be spread among the system nodes. This facilitates different kinds of algorithms as available information is more reliable by nature [6] and [7].

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9. REGULATION AND STANDARDIZATION

The E^3 project intends to push the evolution of the next generation Cognitive Radio and Network standards and to feed the relevant regulatory bodies with the associated and necessary contributions. In its current phase the project has developed the following strategy. The main efforts dedicated to regulation and standardization are focused on WRC-11 agenda item 1.19, on the Reconfigurable Radio Systems (RRS) group in ETSI, and on IEEE 1900.4 within the IEEE Standards Coordinating Committee 41 (SCC41). The work items needing consideration within the working groups of RRS have been identified and most of them are lead by E^3; these include in particular those affecting potential harmonized standards applicable to SDR/CR equipment.

From the regulatory perspective, the strategy targets are to identify and efficiently impact the most relevant bodies. A careful analysis of the different possible paths has lead to the conclusion that this will happen, as far as ITU and WRC-11 are concerned, through the CPG PT A (conference preparatory group). During last ITU-R WP 5A meeting (February 08) two input contributions were proposed by E^3 under the name of some of its partners. Moreover, E^3 is also carefully monitoring or contributing to the progress in the different ECC working groups i.e. WG RA (Regulatory Affairs) for the development of the "responsibility chain" concept, WG FM (Frequency Management) and WG SE (Spectrum Engineering) for Dynamic Spectrum Access. The TCAM specific TGS sub-group (TCAM Group on SDR) on SDR regulation with respect to the R&TTE Directive is also under consideration.

10. CONCLUSIONS

An update on targets, approach and first results of the FP7 Integrating Research Project E^3 was given. Technical, business, standardization and regulatory perspectives were presented and detailed, showing how E^3 is addressing the vision of a heterogeneous wireless network designed for a smooth evolution from existing Radio Access Technologies towards novel standards, such as the ones building the framework of IMT-Advanced. Approaches for definition of the system architecture and technical use cases have been outlined. Key enabling techniques such as the CPC, collaborative as well as autonomous methods for RRM and introduction of SELF- X functionalities were introduced. Finally, an overview of the current standardization and regulation landscape is given and it has been shown how E^3 is contributing to the standards relevant for the convergence of future wireless systems.

11. ACKNOWLEDGMENT

This work was performed in project E^3 which has received research funding from the Community's Seventh Framework programme. This paper reflects only the authors' views and the Community is not liable for any use that may be made of the information contained therein. The contributions of colleagues from E^3 consortium are hereby acknowledged.

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