The E3 architecture for future cognitive mobile networks

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Abstract — **Next generation mobile and wireless systems will enhance the operators' network management capabilities and will considerably improve the users' experience. However, these systems form a complex heterogeneous environment that calls for new management techniques targeting efficiency, robustness and adaptability. Cognition techniques as well as the ability for network components to act autonomously are considered as the main tools to achieve these goals. In this paper we present the functional architecture (FA) for the management and control of reconfigurable radio systems of the EU funded IP project called "E3 – End to End Efficiency" that has been designed to enhance existing procedures usually performed in traditional O&M systems (e.g., spectrum management, network planning, configuration actions etc). We present the rational of our design and provide specific examples to illustrate the role of the different functional entities and their interfaces. A considerable part of this architecture has been recently approved as a feasibility study by ETSI Reconfigurable Radio System (RRS).**

Keywords: congitive networks, self-x, reconfiguration, spectrum management, network planning

I. INTRODUCTION

Network management has been a well established procedure for legacy telecommunication systems. However, future mobile and wireless systems will operate in a far more complex environment where multiple standards will coexist (e.g., [1], [2]) while terminals will be equipped with a higher level of capabilities. In this environment it is of paramount importance for the operators and the users to be able to manage their systems in a more dynamic, adaptable and efficient way.

To improve the Operation and Maintenance (O&M) functions new approaches are needed and key enabling technologies are required. One such enabler is the use of cognitive radio technology [3]. Cognitive radio is actually the capability of a wireless network device to be aware of its operational environment and to be able to adapt intelligently its operational parameters and protocols according to this knowledge in new situations in order to achieve predefined objectives (e.g. more efficient utilization of spectrum). Cognition can include mechanisms to learn from previous decisions to improve the performance of actions to be executed in the future. Using this technology, the devices are aware of the network context and can take complex decisions.

Another enabling technology is the introduction of a certain level of autonomic operations by the network components [4]. The goal is to reduce the complexity of O&M procedures, moving from legacy centralized systems to more dynamic and distributed systems. This autonomic functionality enables the realization of several functions such as self-management, self-optimization, self-monitoring, self-repair, and self-protection. Standardization bodies are already pushing towards the notion of self-organizing networks (SON) [5], [11].

The aforementioned technologies are considered to be applied in reconfigurable components [7]. Reconfigurability enables terminals to dynamically modify their operation mode. This capability may span through all the layers of the protocol stack from modulation techniques to error control mechanisms, routing protocols, transport layer mechanisms, video codecs etc.

The goal of the European funded research project called E3 (End-to-End Efficiency) is to use these three enabling technologies (i.e., cognition, adaptability and reconfigurability) as the basis to build innovative and enhanced architectures and mechanisms. The main idea is to blend cognition with autonomic functionalities and use reconfigurable systems to achieve highly intelligent and adaptable network components and mobile terminals. The outcome of this process is a novel architecture that deals with future networks requirements.

The rest of the paper is structured as follows; in section II we provide information on the standardization activities in this area while section III discusses the motivation behind the E3 functional architectural design. The FA of E3 is presented in detail in section IV where we explain the operation capabilities of the new functional blocks. In section V we illustrate how these blocks interoperate during the execution of specific scenarios. We conclude the paper and sketch future research directions in section VI.

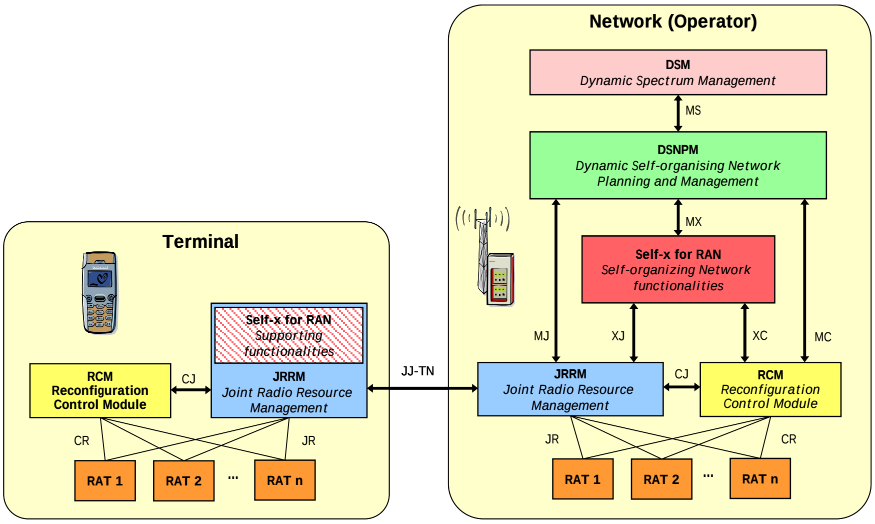

Figure IV-1: Functional Architecture

II. RELATED STANDARDIZATION ACTIVITIES

The definition of a truly operable functional architecture for capturing the stringent requirements of future wireless systems has been under thorough study by various research projects and standardization bodies. Focusing on the latter category, two major standardization activities are identified in the area.

The WG3 of the ETSI RRS TC (Reconfigurable Radio Systems Technical Committee) recently elaborated on a technical report for proposing a generic functional architecture for the management and control of reconfigurable radio systems (including software defined radios as well as cognitive radios) [12], [9]. In May 2009, the ETSI Board has approved this technical report as ETSI TR 102.682 “Functional Architecture (FA) for the Management and Control of Reconfigurable Radio Systems” [6]. A considerable part of the E3 FA has been taken into account in this technical report.

Moreover, the P1900.4 Working Group of the IEEE/SCC41 Committee has recently succeeded to standardize a functional architecture that enables network-device distributed decision making and is targeted to the optimization of radio resource usage in heterogeneous wireless access networks. Special focus was given on dynamic spectrum allocation/access use cases and environments [13], [14].

The architecture defined within E3 can be seen as an amalgamation of the beneficial features from both architectures mentioned above. At the same time, E3 promises to enhance these efforts by examining additional requirements and more importantly introducing advanced cognitive functionalities, as well as self-x functionalities as per the latest 3GPP [5] and NGMN [10] recommendations.

III. MOTIVATION FOR THE E3 ARCHITECTURE

The motivation for the E3 architecture is to improve the utilization of spectrum and radio resources as well as to ease the effort for the configuration of the networks by providing a framework for self-management, self-optimization, self-monitoring, self-repair and self-protection mechanisms.

The architecture assumes a wireless environment with different types of terminals, e.g. legacy terminals, multi-standard radio terminals and cognitive radio terminals as well as different types of base stations like legacy base stations, access points and reconfigurable multi standard base stations.

The functional architecture is additionally designed for an environment where regulation allows a flexible usage of parts of the spectrum. Different spectrum usage rules can be defined for these frequency bands, e.g. which radio access technologies are allowed or the output power values. Additionally, primary/secondary spectrum usage relations can be specified for certain frequency ranges.

The architecture promises to efficiently support different types of QoS, which can be differentiated by a number of parameters such as data rate, error rate, delay, jitter etc. Moreover, the architecture provides the mechanisms to take into consideration additional information such as user preferences (e.g., preferred operator) as well as terminal and network capabilities.

IV. FUNCTIONAL ARCHITECTURE

The functional architecture of E3 consists of a number of distinct functional blocks. These blocks have been proposed through a well defined methodology. In the latter we commenced by defining of a large number of use cases that captured the key concepts of reconfigurability as well as autonomic and cognitive capabilities. Next, the key functionalities implied by the use cases have been identified and grouped according to their similarity thus, resulting in the definition of functional blocks. Finally, interfaces between the functional blocks have been identified and related messages have been defined.

Figure IV-1 presents the functional architecture for the case where a single operator is assumed. The figure presents the functional blocks for the user and the network side.

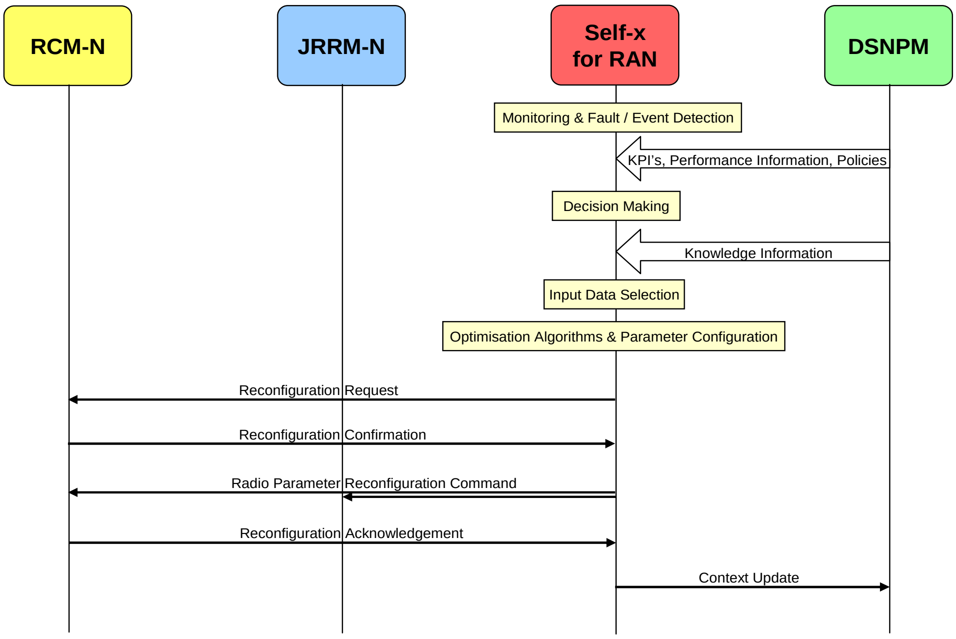

Figure V-1: Message sequences for self-x use cases

On the network side the Dynamic Spectrum Management (DSM) provides the mid- and long-term management of the spectrum (e.g. in the order of hours, days) for the different radio systems. The DSM provides knowledge on the policies for the spectrum assignment, which must include the regulatory framework for the spectrum usage.

The Dynamic Self-Organising Network Planning and Management (DSNPM) provides the medium and long term decision upon the reconfiguration actions of a network segment, by considering certain input information, and by applying optimization functionality, enhanced with learning attributes [8] . The DSNPM for example decides on the optimal configuration of a Flexible Base Station. Such (re)-configuration decisions are then given to the RCM which is then responsible for the execution of the reconfigurations.

The Joint Radio Resource Management (JRRM) performs the joint management of radio resources that might belong to heterogeneous RATs. It selects the best radio access ("Access Selection") for a given user based on the requested QoS (bandwidth, max. delay, real-time/non real-time), radio conditions (e.g. abstracted signal strength/quality, available bandwidth), access network conditions (e.g. cell capacity, current cell load), user preferences, and network policies. JRRM also provides neighbourhood information for the efficient discovery of available accesses.

The Self-x for Radio Access Networks (Self-x for RAN) enables the automation of operational tasks. It targets the self-organising functionalities for the radio access network, mainly providing short to medium term decisions. It focuses on radio access technology specific operator use cases. This functional block cooperates with the DSNPM (regarding Key Performance Indicators – KPIs and policies), with the JRRM (regarding the execution of Self-x for RAN decisions, provision of mesurements) and with the RCM (regarding the various reconfiguration control functions). On the terminal side the block is used mainly to support the self-x operations of the network components (e.g., collecting statistical information). In order to ensure simplicity in our architecture we decided that its communication with its counterpart entity on the network side should be done through JRRM avoiding an excessive and unnecessary number of interfaces between the terminal and the network side.

The Reconfiguration Control Module (RCM) is mainly responsible for the execution of the reconfiguration of a terminal or a base station, following the directives provided by the other building blocks, typically the DSNPM, the Self-x for RAN and the JRRM. It is required in reconfigurable terminals, base stations, and optionally other reconfigurable network elements (e.g. mobility anchors) so as to enforce and realize their adaptation to the current context.

The aforementioned functional blocks follow a cognition loop where a component is continuously monitoring a set of variables related to the network and/or terminal conditions and performance. If an event occurs that needs dealing with (e.g., there are no longer any available resources for a BS, a new radio access technology is detected by a mobile terminal etc) then the component evaluates the collected data and takes a decision to execute an appropriate action. Then, this action is performed and the results from such an operation are recorded and evaluated in order to optimize any future related decisions.

To support the operations of the E3 functional blocks we have identified three "cognition enablers" that assist in the phase of collecting information from the network environment.

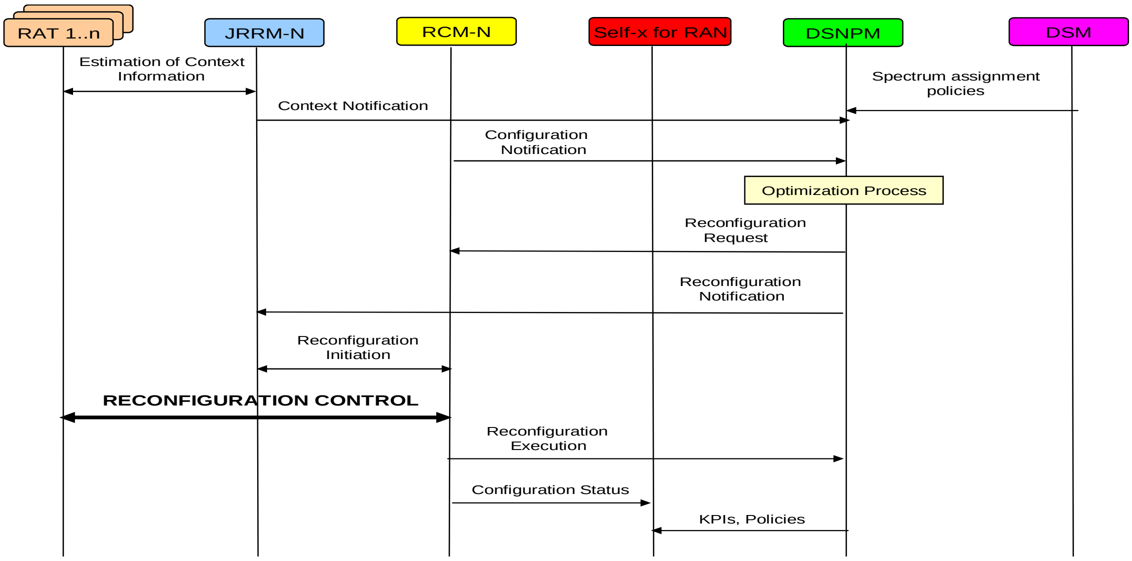

Figure V-2: Message sequences for FBS reconfiguration

Terminals are informed by a logical channel, called the Cognitive Pilot Channel (CPC), about a number of parameters that are needded by the terminals to operate more efficiently such as the available radio access technologies in a geographical area, the frequencies that these technologies are using, etc.

The second enabler is called Cognitive Control Radio (CCR) and is an out-band peer-to-peer communication radio between heterogeneous network nodes (e.g. between terminals or between an acess network and associated terminals) for the exchange of cognition related information. It operates on a known frequency. It is meant for use in unlicensed bands, where cognitive mobile terminals may operate. Note that this “cognitive band” may contain legacy primary users. CCR is like a narrowband ad-hoc wireless LAN complemented with multi-hop networking. Consequently, the PHY and MAC layers designs should focus on the minimization of power consumption.

Finally the third enabler, called Spectrum Sensing (SS), focuses on gaining knowledge related to the available radio systems by sensing, the characterisation of radio conditions and the radio link quality estimation. In cooperation with the CCR or the CPC, SS information can be distributed between different nodes. These three enablers are not depicted in Figure IV-1 since their functionality is considered to be implemented by lower layer protocols.

V. OPERATION EXAMPLES

In this section we present two examples to illustrate the interoperation of the functional blocks presented in the previous section. These examples focus on the operation of the FA on network side thus the suffix of the functional block names is marked with the letter “N”.

Figure V-1 shows, in the form of a message sequence chart, an example applicable for self-x use cases. Such use cases are for example: neighbour cell list optimization, interference control, handover parameter optimization, load balancing, cell outage detection and compensation, etc. [10].

The functional block Self-x for RAN is using Monitoring and Fault/Event Detection procedures to constantly check the network environment status. The Monitoring includes all system measurement reports. The Fault/Event Detection detects whether a fault and/or another event has occurred, e.g. cell outage, cell interference, load unbalancing, misconfiguration, or identification of a new base station, etc. DSNPM supports these procedures and sends KPIs and policies to the Self-x for RAN. The Decision Making decides whether it is necessary to change the system behaviour and selects the optimization algorithms, which are to be taken into account. The Input Data Selection calculates different input metrics and sets the start parameters for the optimization algorithms. Knowledge on former optimization results is taken also into account for the Input Data Selection in order to enhance efficiency of the operation. After the execution of the optimization algorithms and the resulting parameter configuration, the possibility of reconfiguration is checked between Self-x for RAN and RCM-N and a corresponding command is sent to the JRRM-N. After a successful reconfiguration, Self-x for RAN and DSNPM are informed about the new configuration. This procedure is generally applicable for all self-x use cases.

Figure V-2 depicts the cooperation of the different functional blocks and the corresponding sequence of messages, in case of accrued reconfiguration of a number of Flexible Base Stations (FBSs). This example is an evolution of the work presented in [9].

The RAT is the radio access technology that each FBS currently operates. JRRM-N retrieves the appropriate network context information from the different RATs (Estimation of Context Information), which comprises information about the status of the Flexible Base Stations (e.g. the current load and QoS indicators of the supported services). The context information is forwarded to DSNPM (Context Notification).

RCM-N reports the current configuration (e.g. the operating frequency and RAT) and the reconfiguration capabilities (e.g. the set of possible different operating RATs) of the FBSs to DSNPM (Configuration Notification). This notification is sent to DSNPM whenever there is any alteration in message's parameters.

DSNPM, using as input the total aforementioned information sent from JRRM-N and RCM-N, evaluates the network's operation and executes an optimization process, in order to maximize the network's performance (for example in terms of improving QoS metrics and maximizing bandwidth usage) and satisfy user's needs. The process may have as result the necessity of reconfiguration of a number of FBSs. The new selected operating RATs and/or frequencies for these FBSs are in compliance with the spectrum assignment policies, which are derived in DSM and sent to DSNPM. DSNPM requests the reconfiguration of the abovementioned FBSs by RCM-N (Reconfiguration Request) and simultaneously informs JRRM-N for the required reconfigurations (Reconfiguration Notification), in order to ensure the uninterrupted operation of the mobile terminals which are currently connected with the FBSs that will be reconfigured.

JRRM-N and RCM-N cooperate for the reconfiguration of the FBSs. Specifically, JRRM-N determines the suitable moment at which RCM-N initiates the execution of the FBS's reconfiguration (Reconfiguration Initiation). RCM-N enforces and controls all the stages of the reconfiguration procedure and afterwards, informs DSNPM for the successful reconfiguration execution (Reconfiguration Execution), as well as Self-x for RAN for the new status of the reconfigured FBSs (Configuration Status).

Subsequently, DSNPM derives new policies that are sent to Self-x for RAN. These policies constitute the framework of the operation of Self-x for RAN, concerning its decisions for the determination of specific operation parameters of the FBSs, e.g the maximum transmission delay during handover process. Furthermore, DSNPM calculates suitable KPIs and forwards them to Self-x for RAN to support and accelerate its operation.

VI. CONCLUSIONS

The functional architecture of the E3 project for the management and control of reconfigurable radio systems in future cognitive mobile networks was introduced. Based on a specific methodology, the functional blocks both on the terminal and the network side as well as their respective interfaces have been defined and presented. With two specific examples we have illustrated the cooperation between these functional blocks.

A significant part of the functional architecture has been recently approved as a feasibility study by ETSI Reconfigurable Radio System. The next step in our work is the detailed definition of all the messages that are exchanged between the functional blocks during a series of different network management procedures. Moreover, a mapping of the functional blocks into network components is also ongoing in order to ensure that the work undertaken in the E3 project will be harmonized with the related activities in the standardization bodies.

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