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Poster Paper

Functional Architecture for Cognitive Wireless Systems in the B3G World

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Abstract: This paper presents the status of the functional architecture developed within the "E3 – End to End Efficiency" Project by end of 2008. The goal of this architecture is to enhance existing procedures usually performed in traditional O&M systems, with new functions for dynamic spectrum management, network planning, and configuration actions caused by the deployment of additional network components. This extension is achieved by well defined distributed entities that a) monitor their environment and collect appropriate information, b) take intelligent decisions and have the ability to behave autonomously and c) are capable of learning from these decisions in order to improve their future operation. With the implementation of these functionalities we can achieve an improvement of the user quality perception in volatile radio conditions as well as an optimization in the use of the network resources.

Keywords: Functional Architecture, End-to-End Efficiency, cognitive components, autonomic operation, self-organization.

1. Introduction

We are currently witnessing a continuous work to improve the capabilities of mobile and wireless systems. Standardization bodies such as 3GPP [8] are already working on future network systems that will integrate a range of wireless access technologies [1], [2]. The plethora of network technologies combined with the increased capabilities of the mobile terminals creates a complex and heterogeneous environment that cannot be dealt with legacy systems and network management procedures.

In order to evolve network components and procedures key enablers 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 the environment it operates and to be able to adapt intelligently in new situations. Cognition can include mechanisms to learn from previous decisions to improve the performance of actions to be executed in the future.

Another enabler is the use of autonomic network components [4]. The goal is to enhance network components with a set of attributes essential for autonomic communication such as self-management, self-optimization, self-monitoring, self-repair, and self-protection. Standardization bodies are already pushing towards self-organizing networks (SON) [5], [11].

The goal of E3 is to use these enablers as the basis to build innovative and enhanced architectures and mechanisms, extending prior work on reconfigurability [6]. Thus we have followed a specific methodology starting with the definition of a number of use cases. As a next step we identified the different functionalities implied by the use cases. We have grouped similar functionalities into building blocks, defined interfaces between them as well as the appropriate messages. Then we have mapped these building blocks onto existing network components. Part of this work is presented in this paper.

In section 2 a high level view of the E3 architecture is presented. In section 3 each identified building block is thoroughly described while in section 4 we attempt to map them onto existing network components. Finally, in section 5 we provide a first draft set of interfaces and reference points between the building blocks, as derived by a set of message exchange diagrams. We conclude the paper in section 6.

2. High Level View of the E3 Functional Architecture

The overall E3 Architecture as specified during the first year of the project is depicted in Figure 2-1. This high level architecture captures the main functionalities E3 is supporting and has been derived from an extensive set of use cases.

The architecture is presented on a two dimensional space. The horizontal axis corresponds to E3 architectural pillars, namely Reconfiguration Management, Cognition Enablers, Spectrum Management, Autonomic Radio Entity Management, Cognitive Radio Access Network Optimisation and Radio Resource Management.

The various deployment cases of the E3 architecture are indicated on the vertical axis. Specifically, from top to bottom, the following telecom environment cases appear: Multi/Meta Operator, Single Operator, Multi Radio, Radio Technology Specific and Vendor Specific HW/SW. E3 attempts to embrace and address all these cases through a single architectural approach.

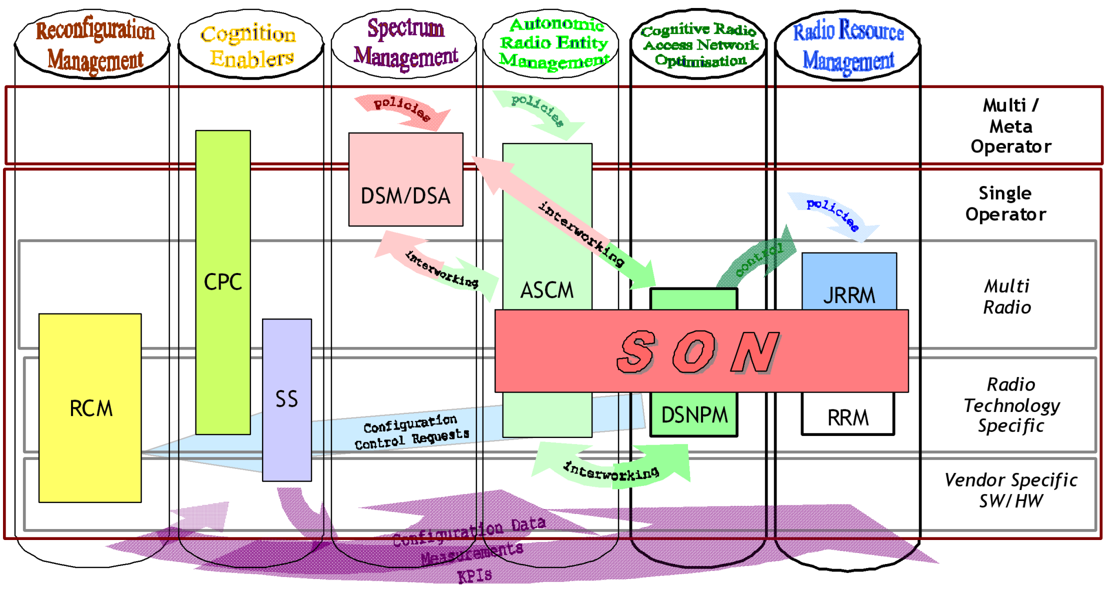

Figure 2-1: The 6 pillars of the E3 Cognitive Radio Architecture

Each pillar captures a specific area of the E3 project. Within each one there are one or more Building Blocks. Each Building Block is positioned inside a pillar according to the cases that is envisaged to address. Consequently, we have the following Building Blocks: The Reconfiguration Control and Management (RCM), the Cognitive Pilot Channel (CPC), the Spectrum Sensing (SS), the Dynamic Spectrum Management/Allocation (DSM/DSA), the Autonomic and Self-Organizing Cognitive Management, the Dynamic Self-organizing Network Planning Management (DSNPM), the Joint Radio Resource Management (JRRM) and the Radio Resource Management (RRM).

The horizontal Self-organizing Network (SON) block that traverses the ASCM, DSNPM, JRRM and RRM building blocks, highlights the existence of this kind of functionality. Obviously the capabilities of autonomicity and dynamicity that characterize

ASCM and DSNPM respectively as well as the decision making capability of JRRM and RRM, are prerequisites of self-x functionality. Consequently, the fact that SON capability is supported and realized by these three pillars is highlighted with a building block orthogonal to the rest. The detailed implementation of SON will be subject of further consideration.

3. Building Blocks Presentation

In the context of this section, the aforementioned building blocks are presented in detail. Each subsection commences with an outline of each block's identified functionality and proceeds in presenting the functional entities (FE) it comprises.

3.1 Reconfiguration Management and Control

The Reconfiguration Control and Management (RCM) building block encompasses functionality for enforcing/executing reconfiguration actions on a network component. It incorporates legacy SDR functions, protocol components download, installation and configuration, self-healing actions (e.g. resetting hardware, installing software patches) and finally performs the actions to form an ad-hoc network if this is desired. RCM focuses on the efficient and effective planning of reconfiguration, meaning the selection and deployment of the most appropriate actions with respect to available contextual information. It has to be stated at this point that RCM itself receives the general directives from other modules, typically the ASCM and the DSNPM; consequently it acts as the enforcement point of reconfiguration decisions made by other building blocks. The functional entities comprising this block appear in Figure 3-1.

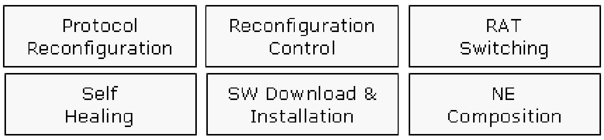

Figure 3-1: Functional Entities of RCM. RAT and NE are abbreviations of Radio Access Technology and Network Element respectively.

3.2 Cognitive Pilot Channel

The Cognitive Pilot Channel (CPC) [7] supports the efficient discovery of the available radio access technologies and reconfiguration management in heterogeneous wireless environments between network and user terminals. The CPC may consist of two components, hereafter called out-band CPC and in-band CPC. The former is a physical channel that does not belong to any radio access technology, whereas the latter refers to a logical channel within a deployed radio access technology. The CPC carries information such as the available operators, RATs, and operating frequencies in specific locations.

3.3 Spectrum Sensing

Spectrum sensing aims at monitoring the operating channel and potential backup channels. The objective is to detect the appearance of a primary user in any of those channels. Once detected, the channel is considered occupied. If a primary signal is detected on the operating channel, the channel should be vacated and the operation be moved to a backup channel. Another objective in some cases is to detect unused periods in another radio system with the aim of using those periods opportunistically. This target requires high-speed characteristics from the sensor. Wideband spectrum estimation is used to scan rapidly the spectrum. It is expected that with this technique signals deep below noise cannot be detected. The sensor classifies the spectrum to occupied and potentially vacant spaces. Narrowband spectrum sensing is required to further analyze the potentially vacant spaces.

3.4 Dynamic Spectrum Management

The Dynamic Spectrum Management block targets the mid- and long-term management (e.g. in the order of hours, days) of the spectrum resources for the different systems. It exposes knowledge management functionalities related to policies for the spectrum assignment as well as the current status of spectrum assignment. The latter directly supports the trading capability of this block. Additionally it incorporates a decision-making capability regarding the spectrum assignment to certain RATs. Finally, DSM is able to negotiate with other DSM instances, belonging to different operators, on spectrum assignment issues. The functional entities comprising this block appear in Figure 3-2.

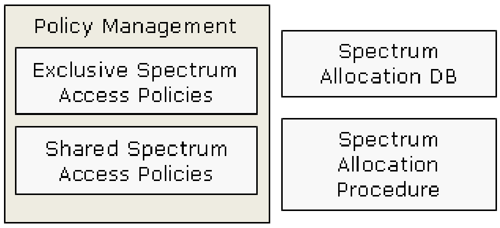

Figure 3-2: Functional Entities of DSM. DB is the abbreviation of Data Base.

3.5 Autonomic and Self-Organizing Cognitive Management

The Autonomic and Self-organizing Cognitive Management (ASCM) Building Block targets the autonomic operation of cognitive radio system entities for achieving an optimal system performance. More specifically, ASCM is responsible for improving the operation of specific devices based on appropriate contextual information of the radio system entity and the environment. In contrast to other functional blocks in the system that focus on overall network performance optimization, ASCM decides based on policies related to the operation of single entities in relation to computing (e.g. memory, CPU usage, power consumption) as well as network resources. It is a cognition-enabled module that makes smart decisions based on previous data and current system and network conditions. The functional entities comprising this block appear in Figure 3-3. The different colours appearing in the figure highlight Utility Functions and building block Specific Functions. The former is a term describing functionality that is common across various building blocks, while the latter encloses functionality related to ASCM operations.

Figure 3-3: Functional Entities of ASCM. KPI is an abbreviation for Key Performance Indicator.

3.6 Dynamic Self-Organizing Network Planning and Management

Within the Cognitive Radio Access Network Optimisation functional area the Building Block Dynamic Self-organising Network Planning Management (DSNPM) has been identified. It can be seen as the enhancement of the E2R II functional block Dynamic Network Planning and Management (DNPM) [9] with additional self-x and learning capabilities in particular for the realization of SON functionalities. DSNPM aims at the knowledge-based, reactive or proactive, handling of contexts (whereas DNPM in E2R II [10] was reactive handling). The first set of outputs of DSNPM comprise the interconnection of network elements (backhaul selection or mesh), the distribution of traffic to RATs and networks, the QoS assignment to user/service classes and the overall network performance optimization. Additionally, DSNPM is involved with the actions of: RAT selection and activation, spectrum selection, and radio parameter re-configuration. The decision-making part which is responsible for such decisions consists of optimisation algorithms, applicable in the mid-term, and incorporate advanced knowledge management schemes pertinent to machine-learning, knowledge representation and reasoning. The decision-making part requires input that comprises the context of operation from the Context Management building block (statistics on the traffic, mobility and interference conditions, as well as network status), a set of policies (rules, constraints) from the Policy Management building block, and profile information from the Profile Management building block, respectively (user-classes, applications, network equipment). Context and knowledge management blocks can be also used for knowledge sharing, and for cooperating with other entities in the handling of new or anticipated contexts. Consequently, a basic split into the functional entities comprising this block appears in Figure 3-4.

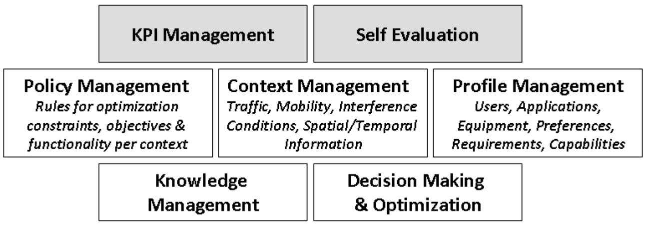

Figure 3-4: Functional Entities of DSNPM

3.7 Joint Radio Resource Management

The main functionalities of joint radio resource management (JRRM) are neighbourhood information provision for efficient discovery of available accesses, access selection in both connected and idle state, radio resource and link performance monitoring, and management of policies related to the joint administration of radio resources. Access selection functionality can be based on the requested QoS (bandwidth, maximum delay, real-time/non-real-time), the 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. In order to support neighbourhood information provision, the system may have a database storing the location of all radio accesses (cells) including information on cell location (longitude/latitude), cell size (e.g. radius of the cell), cell capabilities (support of e.g. real time, non-real time services), cell capacity, and dynamic data (e.g. current cell load). Figure 3-5 illustrates the functional entities of JRRM.

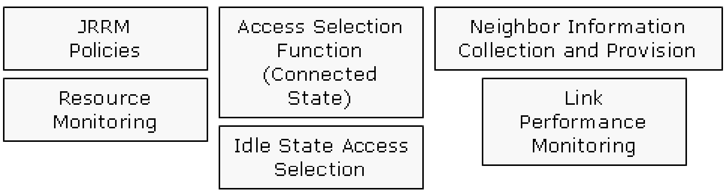

Figure 3-5: Functional Entities of JRRM

4. Mapping of Building Blocks onto Network Components

In this section, we present a mapping of the previously defined building blocks onto network components of the LTE-SAE architecture. Figure 4-1 illustrates the placement of Building Block functionalities in the network components. As it can be seen, RCM functionalities are placed in all the reconfigurable devices (i.e. the mobile device, the Flexible Base Station, the SAE Serving Gateway and the PDN Gateway as well as the IP routers that will serve trusted and untrusted non-3GPP access networks). These devices will be able to execute the reconfiguration actions to support decisions made by other Building Blocks (e.g. reconfiguration of protocol stack by ASCM).

As far as ASCM functionalities are concerned, they are placed in the mobile terminals, the Flexible Base Stations (e.g. RAT Selection, self optimization, monitoring and collecting information), the ASN Gateway for trusted non-3GPP IP Access networks, the ANDSF (e.g., for the network discovery and selection functionality), and the O&M entity (e.g. managing policies).

The CPC information to be advertised will be provided by the JRRM and/or the DSNPM towards the base stations sending out the CPC information. Additionally, CPC functionality is also located in the terminal, e.g. to receive the broadcasted CPC information or to send CPC requests on the uplink.

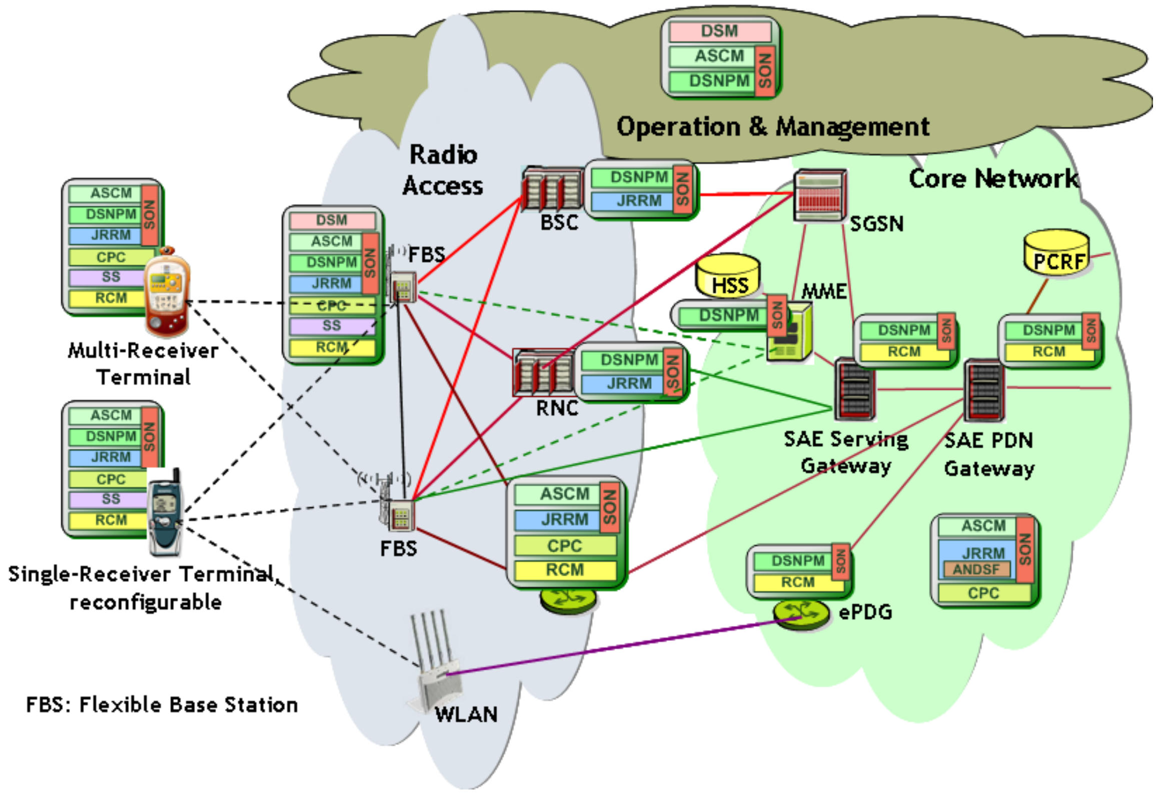

Figure 4-1: Mapping of functional blocks onto network components

Spectrum Sensing (SS) is implemented in Flexible Base Stations (FBS) and User Equipment (UE). It is able to perform wideband and narrow band sensing. It also processes the sensing results for collaborative spectrum sensing and changes the format of the results suitable for DSNPM.

JRRM functionality is distributed between the terminal and the network. On terminal side, the JRRM-TE makes measurements on link performance as well as idle state access selection. In the connected state, the access selection is made together with the JRRM on network side. There, different options exist where the JRRM can be located. JRRM functionality is typically located in the base stations (e.g. eNodeB) or the Base Station Controllers (e.g. RNC) while additional parts of its functionality - as discussed in 3GPP under the term ANDSF - can be located more centrally.

DSNPM functionalities are placed in O&M, in the Evolved Packet Core (MME, Serving GW and PDN GW), in the evolved RAN (FBS) and in the UE. Execution of e.g. specific Policy Management Functionalities might be executed by PCRF and/or HSS.

The DSM function is located in the O&M, where it provides a framework of operator policies and legal constraints how the spectrum can be used in the network. The final decision on which spectrum to be used in a base station, is then made inside the RAN (FBS) in cooperation with the DSNPM.

5. Reference Points / Interfaces

The introduction of reference points / interfaces is the next step in architecture specification. The location of these interfaces is shown in Figure 5-1 for a single-operator case, and in Figure 5-2 for a multiple-operator case.

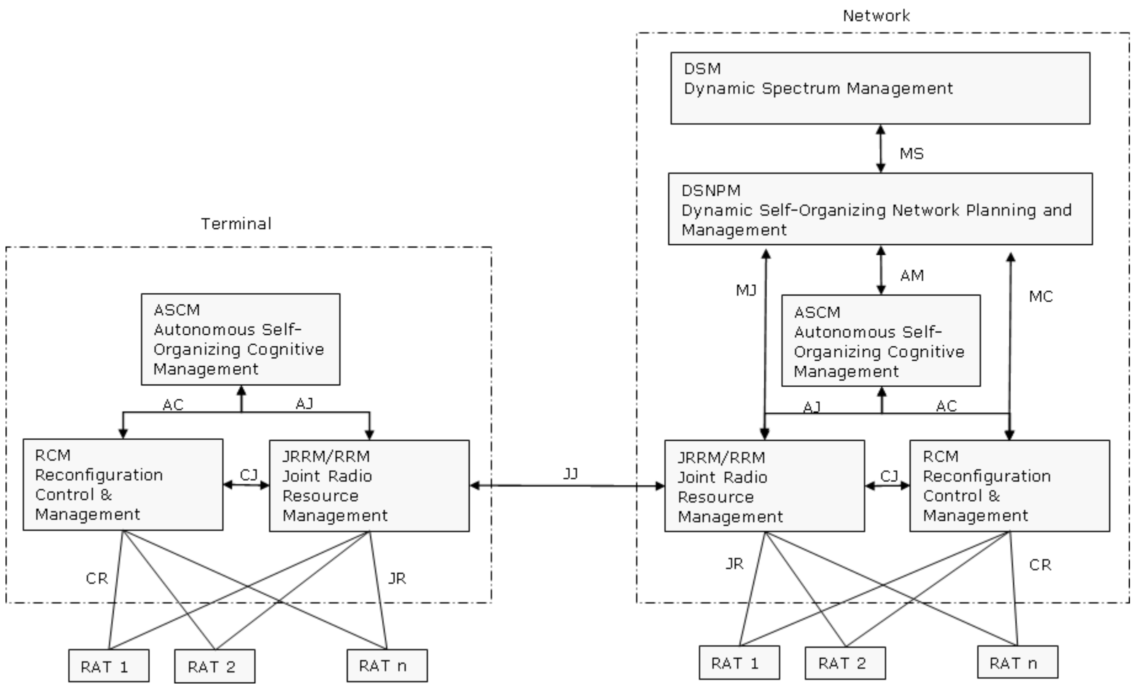

Figure 5-1: Functional architecture – single operator case

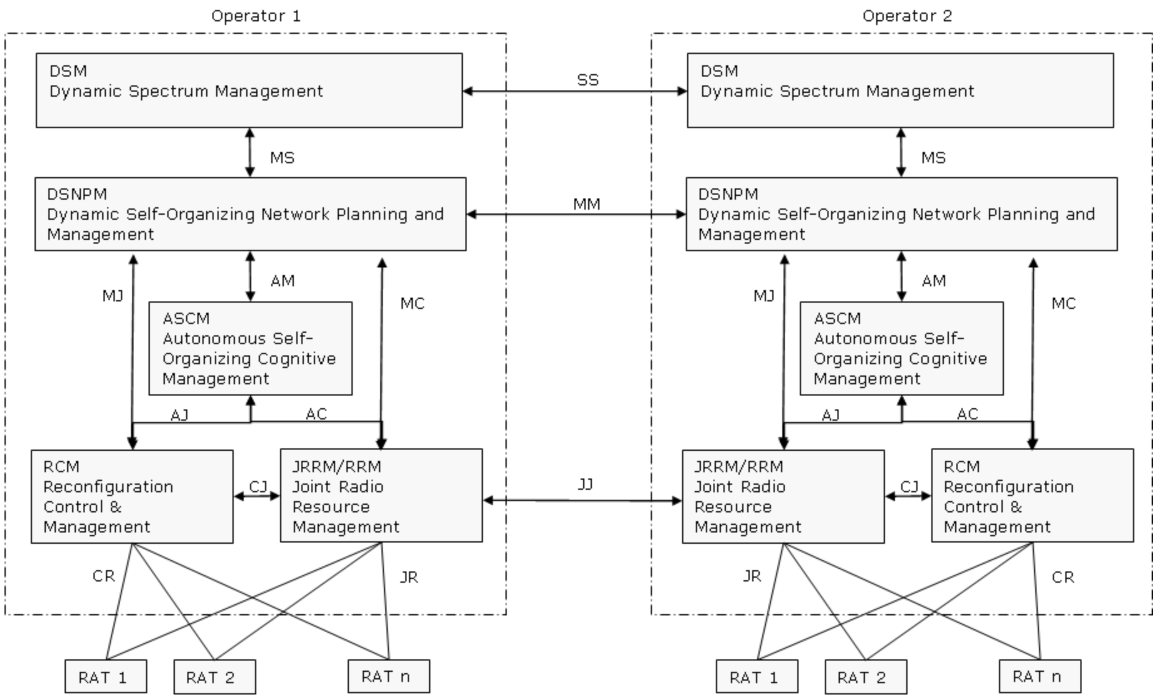

Figure 5-2: Functional architecture, network side – multiple operator case

In the case of a single operator, the network includes all E3 Building block functionalities, whereas the terminal embodies the ASCM, RCM, and JRRM functional entities. Interactions between DSM and DSNPM are needed on the network side for the exchange of spectrum-related information. The DSNPM block communicates with a) the ASCM for self-management scenarios, b) the JRRM for decision-making and execution of actions related to the joint management of radio resources, and c) the RCM for the enforcement of reconfiguration actions, such as software upgrades and spectrum hopping commands. Self-configuration actions dictate the interaction between the ASCM and JRRM/RCM modules.

Figure 5-2 illustrates the interfaces necessary in a multi-operator case. The *SS* interface is used for inter-operator spectrum rental (e.g. based on spectrum auctions). The *MM* interface can be used for the exchange of non-sensitive planning information between operators. Finally, the *JJ* interface connects two JRRM instances, which may cooperate for handover and/or load balancing purposes. For example, when a network segment of an operator that has deployed multiple RATs is overloaded, some traffic can be diverted to a network of another operator that has also deployed multiple RATs in the same geographical area.

6. Conclusions

The architecture developed during the first year of the E3 project is presented. This architecture will be refined during the second year, taking into account the overall E3 project work. The task of producing this architecture is very challenging since the E3 project deals with a large number of advanced functionalities that aim to enhance the capabilities of future mobile and wireless systems.

The presented architecture combines functionalities related to the Dynamic Self-organizing Network Planning Management, the Dynamic Spectrum Management, the Autonomic and Self-Organizing Cognitive Management, the Reconfiguration Management and Control. These functionalities are supported by information managed and distributed by the Cognitive Pilot Channel and Spectrum Sensing mechanisms. Self-organizing Network (SON) capabilities are considered as well.

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