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derived functional blocks, together with the interfaces among them and their distribution between network and terminals is depicted in Fig. 4. Dynamic Spectrum Management (DSM) block is responsible for the medium and long term, both technical and economical, management of spectrum and as such, it incorporates functionalities like provisioning of information for spectrum assignments, spectrum occupancy evaluation and decision making on spectrum sharing/trading. Dynamic, Self-Organising Planning and Management (DSONPM) caters for the medium and long term management at the level of a reconfigurable network segment (e.g. incorporating several BSs). It provides decision making functionality for QoS assignments, Traffic Distribution, Network performance optimization, RATs activation, configuration of Radio parameters etc. The fundamental objective of the Joint Radio Resources Management (JRRM) block is the joint management of radio resources possibly belonging to heterogeneous RATs and its functionalities mainly include Radio Access Selection, Neighbourhood

Information provision and QoS/bandwidth allocation/admission control. Finally, Configuration Control Module (CCM) is responsible for the enforcement of the reconfiguration decisions typically made by DSONPM and JRRM.

V. ETSI RRS SOFTWARE DEFINED RADIO SOLUTIONS

ETSI RRS considers SDR related standardization for both, Base Stations (BS) and MDs. The BS related work is currently in an early stage and available results are resumed in [10]. The current focus in ETSI RRS WG2 relies mainly on MD SDR related interface standardization between distinct stakeholder domains, such as SDR chipset vendors and MD manufacturers. In this framework, a reference architecture has been derived which outlines the relevant interfaces and concerned building blocks – this architecture, however, is not meant to be normative.

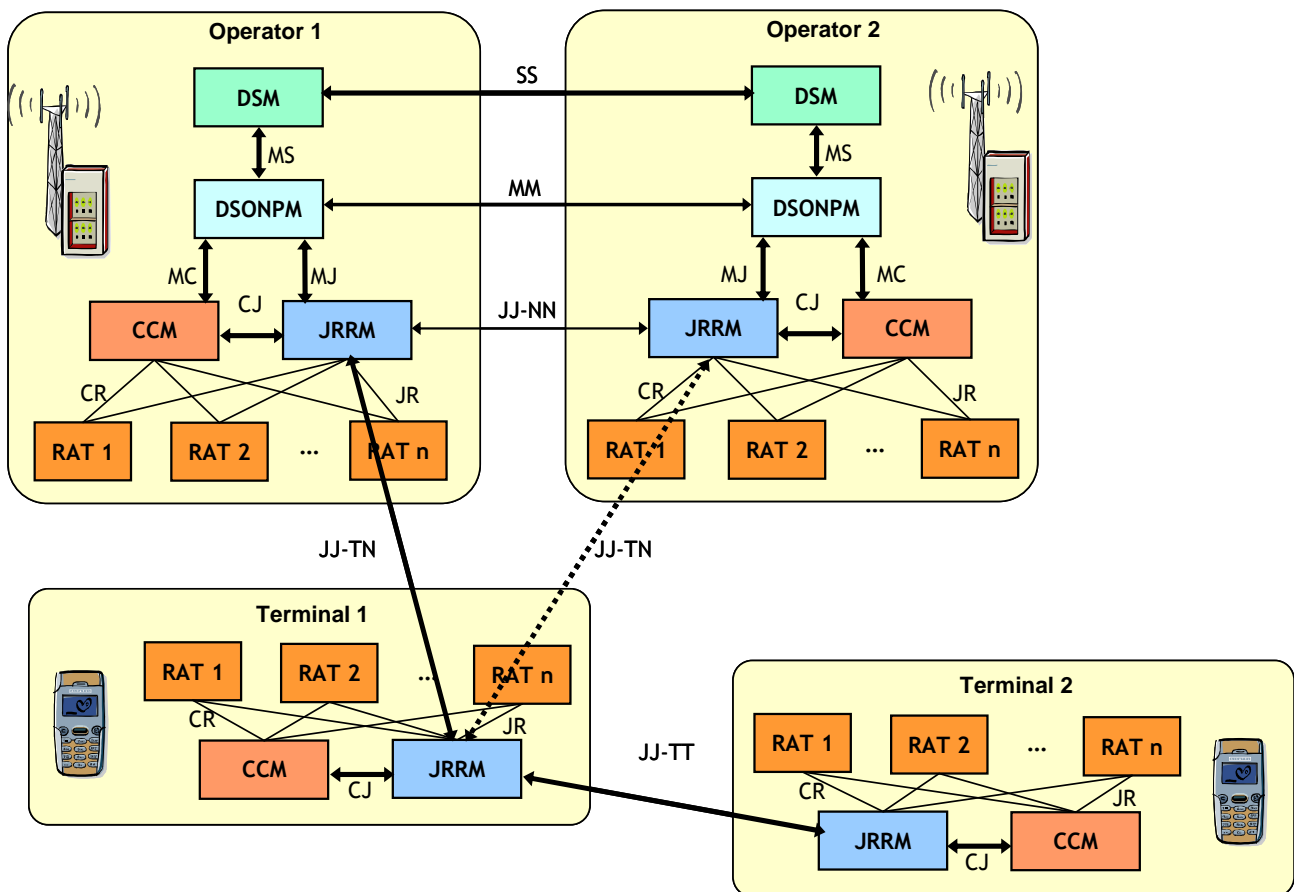


Figure 4: High Level View of the proposed ETSI RRS Functional Architecture.

a) *A SDR Architecture Approach for Mobile Devices as a basis for future SDR Standards*

ETSI RRS has identified a set of requirements related to an SDR MD architecture [11], including i) general architectural requirements, ii) capability requirements, iii) operational requirements, iv) interface requirements and v) other requirements. The capability requirements are highlighted below:

- i) **Multiradio configuration capability:** SDR equipment in mobile device is expected to install, load and activate a radio application while running a set of radio systems already;
- ii) **Multiradio operation capability:** SDR equipment in mobile device is expected to execute a number of radio systems simultaneously by taking into account temporal coexistence rules designed for their common operation;
- iii) **Multiradio resource sharing capability:** SDR equipment in mobile device is expected to execute a number of radio systems simultaneously by sharing computation, memory, communications and RF circuitry resources available on the radio computer platform by using appropriate resource allocation, binding and scheduling mechanisms.

The outcome of the study consists, among others, of the presentation of a functional architecture for SDR equipment as detailed in Fig. 5:

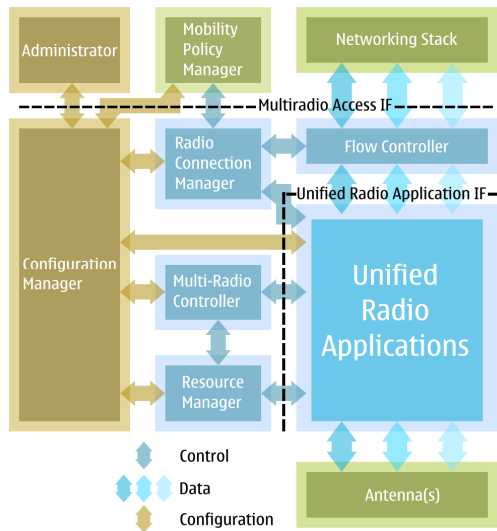


Figure 5: Functional Architecture of SDR Equipment.

The components of this framework have different responsibilities as follows:

- i) **Configuration Manager:** (de)installation and (un)loading of radio applications into radio computer as well as management of and access to the radio parameters of those radio applications;

- ii) **Radio Connection Manager:** (de)activation of radio applications according to user requests and overall management of user data flows;
- iii) **Flow Controller:** sending and receiving of user data packets and controlling the flow;
- iv) **Multiradio Controller:** scheduling the requests on spectrum resources issued by concurrently executing radio applications in order to detect in advance the interoperability problems between them;
- v) **Resource Manager:** management of radio computer resources in order to share them among simultaneously active radio applications, while guaranteeing their real-time requirements.

b) *SDR Standardization related to Interfaces*

The ETSI RRS WG2 SDR handset reference architecture report [11] identifies four candidate interfaces for standardization:

- i) **Multiradio Interface** as the uniform interface for network protocol stacks and other user domain entities to access services of the radio computer;
- ii) **Unified Radio Application Interface** at the boundary between the common radio computer platform and the specific radio applications;
- iii) **Radio Programming Interface** including software development-time concepts and run-time interfaces between radio software entities and radio computer platform;
- iv) **Interface to the Reconfigurable RF Transceiver** to support multiple radio applications, even concurrently.

Among these interfaces, the **Multiradio Interface** has most potential for standardization, and is currently under further studies in ETSI RRS.

The deployment of the **Multiradio Interface** is expected to proceed in phases with platform capability advancing, starting from legacy radio access technologies, gradually moving towards a full SDR:

- i) Radio applications use pre-defined fixed resources. Radio applications come from a single source, and a list of concurrently supported radios is provided. Additional CR functionality is introduced by means of parameter management of individual radio applications;
- ii) Radio applications have fixed resource requirements. Instead of fixed resources, a worst-case resource consumption budget is attached to each radio. The SDR platform does admission check and resource allocation for concurrently running radios, enabling higher resource utilization at the cost of less determinism;
- iii) Radio applications have dynamic resource requirements. In addition to phase 2 capabilities, the resource demand of radios varies based on their type of activity (for instance power-save vs. active data link). Admission control and resource allocation is done whenever a radio changes its behavior classification;

- iv) Radio applications come from third-party vendors. This stage mostly affects the security requirements on the platform, as well as the tools to create radios.

The **Multiradio Interface** is described with a static information model and signaling diagrams for dynamic behavior. This is organized in an UML model to allow formal definitions on a rather abstract level, and extension and specialization of the desired elements later on. Fig. 6 shows an example signaling diagram.

Installation of new a radio application is done by passing a package containing all information and software executables needed to run the radio. Loading of any installed radios may be requested into the execution environment. Parameters of loaded radios may be managed to change the behavior of the radio or to obtain information.

Together with relevant control plane services (such as measuring the radio environment) the management plane services may be used to realize various cognitive radio functionalities.

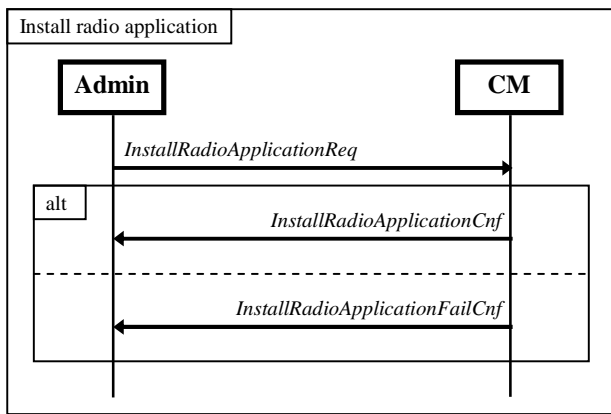


Figure 6: Definition of a service in MURI - Administrator User Requests Installation of a New Radio Application from the Configuration Manager in the SDR Platform.

The information model and service definition for standardization pre-study is ongoing in ETSI RRS. The next step after that is to gather feedback from relevant stakeholders such as chipset and mobile device manufacturers, to determine if there is sufficient interest to begin actual standardization of the multiradio interface.

VI. SECURITY

As a general rule, RRS must validate communication security requirements like Data Confidentiality and Privacy, Availability, Registration, Authentication and Authorization already defined for conventional wireless communication systems. RRS may also be vulnerable to new types of security attacks, beyond the ones already identified for conventional networks.

The SDR reconfiguration capability, as described in section V, where a radio application can be loaded and activated at run time could be exploited by a security attacker to download and activate malicious software modules.

To protect the SDR against these types of attacks, we suggest to adopt Software Assurance processes and functions including a software certification processes, a secure download mechanism, which guarantees the authenticity of the downloaded software, and a secure execution environment in the SDR terminal to guarantee that only trusted software can be activated and executed.

With reference to functional architecture of SDR equipment described in section V, these functions could be implemented by a Software Download Authentication (SDA) component, which can be part of the Administrator and Configuration Manager blocks. SDA may use security functions on the radio, which must be implemented with a suitable level of trust. We may have three levels of interfaces to radio resources: public; group managed; and national (government controlled).

ETSI TC RRS is also investigating security vulnerabilities and threats of Cognitive Radio. Conventional communication systems can only change their transmission parameters and use the RF spectrum bands in the limits implemented in their hardware and firmware architectures. A Cognitive Radio could instead communicate in a wide range of spectrum bands and change its transmission parameters at runtime, on the basis of the sensed radio spectrum environment or the information received from other Cognitive Radio nodes. Because of these capabilities, cognitive radio nodes could increase the risk of harmful wireless interference if the cognitive radio mechanism is disrupted or abused.

As described in section IV.a), cognitive radio networks can be based on the concept of CPC, which can become a vulnerability point by Denial of Service attacks like traffic overload or jamming. Overflow of CPC channel can be controlled through algorithms implemented in the cognitive radio nodes to analyze repetition of cognitive control messages, while jamming of CPC can be mitigated by defining a number of CPC channels in various frequency bands, which could be changed if harmful interference is detected.

The exchange of cognitive control messages could be protected by a distributed authentication protocol and a secure encapsulation protocol to guarantee respectively the sources of cognitive messages and their content. In this area, security solutions designed for the distribution of routing information in mobile ad-hoc networks could be adapted to the exchange of cognitive messages in cognitive radio networks.

VII. OUTLOOK ON FUTURE ETSI RRS TOPICS AND CONCLUSION

Different research lines have been initiated from the academic perspective addressing ETSI RRS aspects. Part of this research is also linked to specific projects such as ICT-E³ [2]. In the sequel, current research trends are highlighted which have the

potential to become relevant for ETSI RRS and CR/SDR standardization in general.

As far as the algorithmic level is concerned, specific algorithms for autonomous RAT selection using advanced tools of game theory, stochastic analysis and decentralized resource allocation are being studied. The cognitive concepts are exploited to carry out dynamic spectrum assignment based on reinforcement learning mechanisms in order to achieve an efficient spectrum usage in the context of next generation mobile flexible networks based on OFDM.

Spectrum sensing has become also a full dedicated topic research in order to continuously monitor and learn the radio environment. The cognitive radio node senses the spectrum to detect any incumbent spectrum users (ISU) to opportunistically utilize it in the spatial, temporal and frequency domains. The key term to be considered here is 'reliably' detecting the ISU as per the regulatory requirements.

Current directions for spectrum sensing involve localization techniques to generate a radio environment map (REM) and keep track of the ISU in the spatio-temporal manner.

As far as the co-existence of primary and secondary networks, several spectrum measurement campaigns have already been performed in diverse locations in Europe and have shown the potential of exploiting free un-used bands. This has permitted to determine the capacity of cognitive networks through the analysis of the spectrum occupancy degree of the allocated spectrum bands in real wireless communication systems. Some specific time and frequency domain models of the spectrum usage have also been derived.

Researchers from academia are discussing in fact beyond the cellular scenario considering more flexible radio communication like peer-to-peer or private femto or hotspot concepts. All these approaches have in common that neither the precise spectrum usage nor the air-interface parameters are known in advance, e.g. using a LTE-like air-interface in ISM spectrum, provided that general coexistence rules on interference power are fulfilled. Obvious advantages of such approaches are multi-user capabilities, embedded broadcast, and concepts of interference handling, system bandwidth scalability, and existing FDD and TDD options.

To give a conclusion, it can be stated that this paper has illustrated the SDR and CR framework that is elaborated by ETSI RRS for a heterogeneous wide area (cellular) and short range system scenario. While these studies are reaching a final stage within ETSI RRS, the next step consists in elaborating corresponding normative standards: From December 2009 on, the group is mandated to produce normative standards in the field of CR and SDR (instead of study reports). The existing study results are expected to provide a broad basis for that effort.

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