ETSI RRS - The Standardization Path to Next Generation Cognitive Radio Systems

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***Abstract*— This paper details the current work status of the ETSI Reconfigurable Radio Systems (RRS) Technical Committee (TC) and gives an outlook on the future evolution. While previous publications have presented an overview of ETSI RRS' main working axes related to i) Cognitive Radio System Aspects, ii) Radio Equipment Architecture (including a Cognitive Pilot Channel (CPC) proposal and a Functional Architecture (FA) for Management and Control of Reconfigurable Radio Systems), iii) Cognitive Management and Control and iv) Public Safety, this document focuses on latest progress related to UHF White Spaces work and the definition of an SDR Handset Architecture. In particular, it is outlined how Cognitive Radio principles can help to adapt existing and/or evolving Radio Standards, such as 3GPP Long Term Evolution, to a possible operation in UHF White Space bands.**

Keywords- Cognitive Radio, Software Defined Radis

I. INTRODUCTION

Cognitive Radio (CR) has first been identified as a preferred technology for high-end applications in the military and public safety domain, since the general CR concept had emerged [1]. Then, a series of research projects investigated means for adapting CR concepts to the needs of civil wide area (cellular) and short-range communication systems, such as IST-E2R I and II, ICT-E3 [2], etc. The involved industrial, regulatory and academic partners were attracted to CR by the prospect of a hugely increased level of spectral efficiency and an improved overall system capacity exploitation, among others, thanks to i) the dual exploitation of spectrum by applying opportunistic spectrum usage, ii) a Mobile Device (MD) being (partially/fully) aware of its (heterogeneous) context (radio context, application context, etc.) and dynamically adapting its parameters such that its operational objectives are reached in an optimum way; e.g., a MD is aware of surrounding Radio Access Technologies (RATs) and selects those which guarantee to fulfill its Quality of Service (QoS) requirements at the lowest cost. Software Defined Radio (SDR), on the other hand, is considered to be an "enabling technology" introducing the required level of flexibility in order to "enable" a device to adapt to its context.

Following CR related rulemaking by the Federal Communications Commission (FCC) [3], several CR standards are currently under development, mainly within the IEEE and ETSI framework. In particular recent clarifications on system requirements for exploiting TV White Spaces (TVWS) as Secondary User (SU) has triggered a new series of standards activities – to give a few examples: IEEE 802.11af defines modifications to both the 802.11 physical layers (PHY) and the 802.11 Medium Access Control Layer (MAC), to meet the legal requirements for channel access and coexistence in the TV White Space. IEEE SCC41 currently examines the set-up of a new activity defining a White Space (WS) system with possible operation in WS bands not limited to TVWS; also, IEEE SCC41 currently extends available system approaches on *Enabling Network-Device Distributed Decision Making for Optimized Radio Resource Usage in Heterogeneous Wireless Access Networks* to TVWS [4].

In this context, the ETSI Reconfigurable Radio Systems (ETSI RRS) Technical Committee (TC) follows a strategy that is complementary to other existing activities. Instead of elaborating a solution to a very specific and focused technical problem (e.g., how to operate WiFi in TVWS (IEEE 802.11af) ?, etc.), ETSI RRS considers the introduction of Cognitive

Radio Systems (CRS) as a whole based on a top-down approach. The related main working axes have been published previously [5,6] and the overall system vision is outlined in [7]. Most recently, ETSI RRS has achieved major progress in the areas of an efficient SDR Mobile Devices Architecture and TVWS usage, in particular with a focus on the adaptation of existing and/or evolving Radio Standards, such as 3GPP Long Term Evolution (3GPP LTE), to a possible operation in UHF White Space bands. The corresponding work progress on these selected topics will be detailed by this paper.

The sequel of the paper is organized as follows: Section II gives a general overview on the ETSI RRS structure, comments on the European Regulatory Framework and gives a general overview on the ETSI RRS concept and vision. Section III details CR aspects focusing in particular on TVWS usage and Section IV presents most recent results on the ETSI RRS Mobile Device (MD) SDR Architecture enabling an efficient (simultaneous) operation of Radio Access Technologies (RATs). Finally, Section V gives an outlook on future topics based on current progress in academic research and a conclusion.

II. ETSI RRS Overview and Cognitive Radio System Concept

At the inaugural meeting, the ETSI RRS TC created the following four Working Groups (WGs), in which the technical discussions are organized and reports are produced (see Fig. 1):

i) **WG1** focuses on "**System Aspects**" and develops proposals from a system aspects point of view for a common framework in TC RRS with the aims to guarantee coherence among the different TC RRS WGs and to avoid overlapping and gaps between related activities.

ii) **WG2** focuses on SDR technology with a particular interest in "**Radio Equipment Architecture**" and proposes common reference architectures for SDR/CR radio equipments (mobile handset devices, radio base stations, etc.), related interfaces, etc.

iii) **WG3** focuses on "**Cognitive Management and Control**"; the group collects and defines the system functionalities for Reconfigurable Radio Systems which are related to the Spectrum Management and Joint Radio Resource Management across heterogeneous access technologies. Furthermore, the group has developed a Functional Architecture for the Management and Control for Reconfigurable Radio Systems as well as a report on the Cognitive Pilot Channel as an enabler to support the management of the RRS.

iv) **WG4** focuses on "**Public Safety**" and collects and defines the related RRS requirements from relevant stakeholders in the Public Safety and Defense domain. The group defines the system aspects for the applications of RRS in Public Safety and Defense.

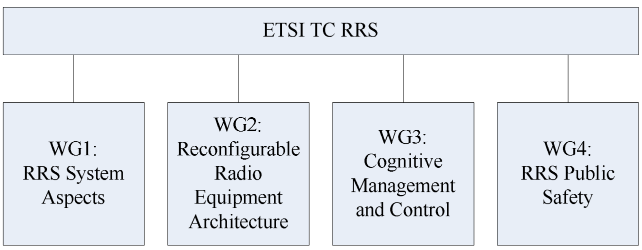

Figure 1: ETSI RRS Structure.

Building on this structure, ETSI RRS will complement ongoing effort in other bodies, such as IEEE standardization bodies, by proposing technological solutions beyond the existing scope (related to SDR interfaces, CR specific Management and Control architectures and interfaces, knowledge management via a Cognitive Pilot Channel and Security solutions); furthermore, ETSI RRS fulfills a key role in the framework of European Regulation, with a focus, among other aspects, on the following:

i) The R&TTE Directive regime in force in Europe is based on declaration of conformity and does include neither type approval nor registration of the equipment nor equipment identifier (in the US, type approval is still necessary). This self-declaration is preferably a reference to a Harmonised Standard to be developed by ESTI RRS;

ii) Protection of TV bands: In Europe, DVB-T does not show a residual carrier as it is the case in the US (the possibility for detection of the US ATSC signal below noise (i.e., at -114 dBm) is made possible thanks to the residual carrier which is present in the ATSC signal). A corresponding adaptation of sensing based standards needs to be defined for Europe;

iii) Broadcasting, wireless microphones and assignment to radio stations are managed in Europe at the national level. Any sharing scheme based on a database will require some level of integration of the national data.

In order to address the above and other European Regulatory aspects, the Electronic Communications Committee (ECC) within the European Conference of Postal and Telecommunications Administrations (CEPT) has set up the SE43 group on "*Technical and operational requirements for the operation of cognitive radio systems in the 'white spaces' of the frequency band 470-790 MHz*" which will form the basis for any future regulation for the potential use of TVWS. ETSI RRS is the competence center within ETSI to implement those regulatory requirements into standards.

In today's composite radio environment a crucial point to enable optimisation of radio resource usage is the cognitive capability of the network and terminal allowing them to switch to the most appropriate technology and frequency for the required service. This becomes even more important in a flexible spectrum management framework, where the spectrum allocated to the different RATs is foreseen to change dynamically within a range of different frequencies.

The overall cognitive radio system concept developed by ETSI RRS is detailed in [7]. It covers both centralized and decentralized solutions for CR systems, where the centralized, operator-driven solution is targeted for wide area utilization, and the decentralized solution is targeted for local area ad-hoc/mesh networking.

The spectrum awareness becomes a basic challenge in such generic scenario, where a number of transceivers even with flexible time-varying assignment of operating frequency and/or RAT are deployed. In this context, collaboration between network and terminals is very important. In order to provide such collaboration, the concept of a Cognitive Pilot Channel (CPC) has been developed for the centralized CR system solutions [8-10]. As detailed in the sequel, ETSI RRS is further refining the CPC concept and presents study results related to a Functional Architecture (FA) for Management and Control of Reconfigurable Radio Systems, including Dynamic Self-Organising Planning and Management, Dynamic Spectrum Management, Joint Radio Resource Management. A complementary mechanism for decentralized CR systems, called Cognitive Control Radio, is described in [7].

III. Cognitive Radio in TV White Spaces

ETSI RRS currently considers the usage of TVWS for adapting existing and/or evolving Radio Standards, such as 3GPP Long Term Evolution, to a possible operation in UHF White Space bands. The following Use Case is given as an example:

Multimode user terminals (i.e. terminals that support multi-RAT in licensed spectrums for instance HSPA and LTE) are also provided with the capability of accessing TVWS spectrum bands in order to provide wireless broadband access (e.g. TD-LTE) for instance in rural areas where high data rate connections are commonly not available. This use case takes the benefit of the excellent propagation performance of a radio network operating in TV White Space frequency bands i.e. 470-790 MHz in Europe/Region 1. TDD can be considered suitable for a secondary/overlay spectrum access compared with FDD.

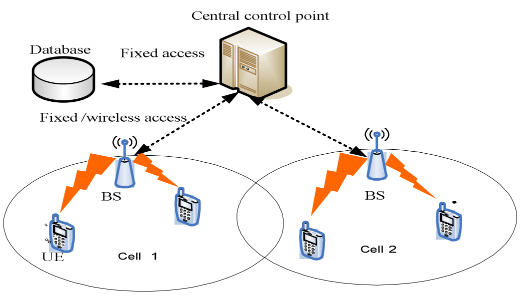

Figure 2: Database driven Access to TVWS.

A network centric solution is considered in regards of allocating available TVWS for the user terminal to get connectivity. In this scenario, available TVWS frequency band is considered based on location rather than in time, it is assumed that TVWS would be largely available in rural area and in time. However, a dynamic change in the availability of the bands can not be excluded and thus shall be taken into account by the system. In the case of a Network Centric solution, the terminal can get the required information from its currehnt connectivity and its current RAT i.e. TD-LTE operating in TVWS, or from another RAT e.g. HSPA in 3G bands. The general principles are illustrated by Fig. 2.

The optimization of Radio Resource usage in proposed to be performed as follows:

i) eNodeB operating on the TD-LTE frequency sends TVWS Allocation Request to the central control point periodically;
ii) The central control point inquires the database if there are any available TVWS frequency bands at the location of the eNodeB;
iii) If available TVWS frequency existing at the location of eNodeB, the central control point sends TVWS Allocation Response which includes the information of allocated TVWS to the eNodeB. Other configuration parameters may be sent to eNodeB as well. Otherwise, the central control point will notify eNodeB that no TVWS is available at its location;
iv) eNodeB decides to switch the operating frequency to allocated TVWS frequency band and notify UE(s) about the change of the frequency;
v) eNodeB buffers the downlink transmitting packets of the connected mode UE(s) and then switches to the allocated TVWS frequency after all the UE(s) have been informed;
vi) The related UE(s) will switch to the frequency accordingly at the occasion indicated by the eNodeB. The buffered downlink packets in eNodeB are sent to UE(s) in order to ensure the service continuity;
vii) eNodeB sends eNB Configuration Update message including the updated configuration parameters to the central control point. The central control point responds with eNB Configuration Update Ack message to acknowledge that it successfully updated the configuration data;
viii) The central control point sends Database Update Request message including the updated configuration parameters to the database. The database responds with Database Update Ack message to acknowledge that it successfully updated the configuration data.

IV. Mobile Device SDR Architecture

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 [11]. The current focus in ETSI RRS WG2 relies mainly on MD SDR as the underlying implementation technology and enabler for CR, as well as 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 [12].

a) *Use Cases and capabilities for Mobile Device SDR Architecture*

The main use cases which require the availability of a MD SDR architecture as defined by ETSI RRS are as follows:

i) **Terminal-centric configuration in a heterogeneous radio context**: Being in a heterogeneous environment, a given Mobile Device is camping on a single RAT or a set of multiple RATs simultaneously in order to optimize the operational conditions – typically, optimality is defined in the sense of overall power consumption, service reachability, aggregate Quality of Service, subscription cost of links, etc.

ii) **Network-driven terminal configuration in a heterogeneous radio context**: The network is assumed to have knowledge of the heterogeneous radio context and of the configuration capabilities of the Mobile Device. The network decides a single RAT for the MD to camp on, or a set of multiple RATs simultaneously. Finally, the MD is configured correspondingly. The general principle is outlined in Fig. 4.

iii) **Addition of new features, such as support for novel radio systems, to Mobile Devices**: An MD is introduced to the market and the corresponding owner wishes to add new features, in particular the support for new standards, to the device.

iv) **Provision of a new cognitive feature (e.g. cross-technology spectrum measurement)**: Novel systems are constantly under definition and deployment. In order to acquire knowledge about the radio context, Mobile Devices need to adapt their sensing and spectrum measurements correspondingly.

For the SDR equipment ETSI RRS has identified a set capability requirements as they 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.

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

The use cases and capability requirements concern the behavior of mobile devices both on a general level (communication of cognitive functions between devices, radio transport selection, etc.) as well as deep in the implementation (resource sharing, extension of MD functionality, etc.). To enable independent development of these functions, the MD SDR architecture assumes all cross-technology decision making resides on the layers above the SDR subsystem, which in turn provides the necessary services to base the decisions on. Details of SDR implementation are exposed only when needed to realize a use case, and even then in a generic form to preserve as much portability across platforms as possible.

An example information flow between the user entities and the SDR subsystem is shown in Fig. 3 in the network-driven MD configuration use case.

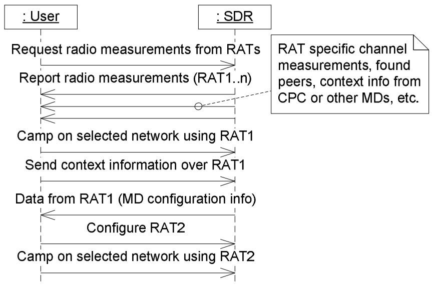

Figure 3: Information flow between SDR subsystem and its user in example case.

The components of the MD SDR architecture 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, which can also be switched from one radio application to another.

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.

c) *SDR Standardization related to Interfaces*

The ETSI RRS WG2 MD SDR reference architecture report [12] identifies four candidate interfaces for standardization:

i) Multiradio Interface (MURI) 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;

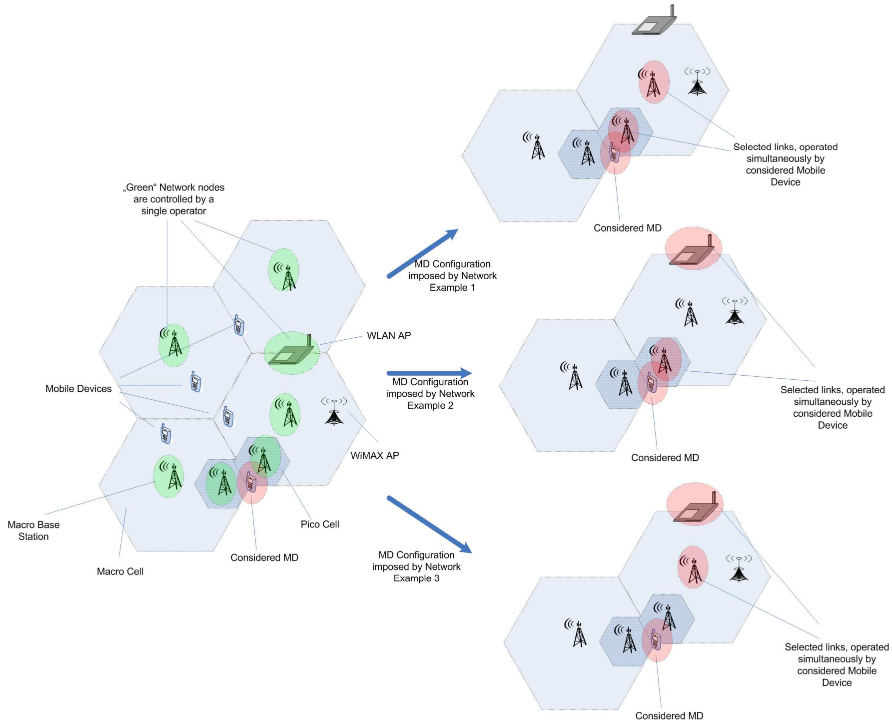

Figure 4: Use case for network driven terminal configuration in heterogeneous radio environment.

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 in ETSI RRS, and is currently under further studies. It is expected to enable an easier integration of radio platforms into handsets that benefits both chipset vendors and device manufacturers; moreover, it offers significant functionality on top of SDR. Common methods of accessing the SDR services ease the definition and deployment of cognitive radio, providing capability to implement the functionality independently on both sides of the interface.

The deployment of the Multiradio Interface is expected to proceed in phases with platform capability advances, starting from legacy RATs, gradually moving towards full SDR:

i) Legacy RAT implementations. At least some of the radios are implemented with non-SDR technology, e.g. with dedicated ASICs, and are resource-wise independent of each other. The Multiradio Interface collects the control and user plane functionalities of the diverse radios in a uniform manner, allowing easier development of architecturally coherent connectivity and mobility management features.

ii) 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;

iii) 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;

iv) 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;

v) 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. 5 shows an example class diagram which is a part of the information model. This information is passed through the MURI using the service requests and responses; here an illustration of the measurement information is given. In order to be compatible with the MD SDR architecture, all RATs must be able to present their discovered devices using the given model – specific parameters like network names and device identifiers may naturally have their RAT specific format. Note that in the initial deployment phases the MURI may be a wrapper around specific legacy interfaces to the RATs, if no Unified Radio Application Interface is in place.

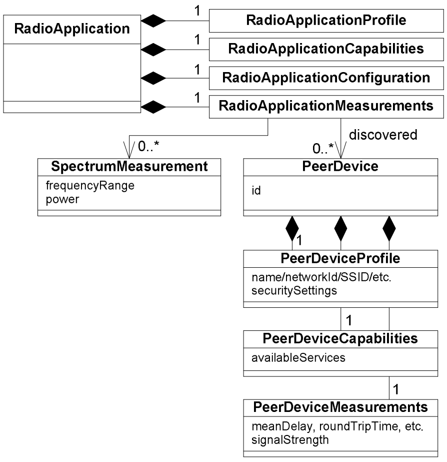

Figure 5: Static information model in MURI – example of measurement information available from RATs.

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.

V. OUTLOOK ON FUTURE TOPICS & CONCLUSION

Considering the options along standardization pathes further topics have to be addressed in order to enable additional functionalities and features.

Decisions and monitoring of band occupation should additionally be accompanied by distributed spectrum sensing techniques in order to cope with hidden terminal and near-far effects. Distributed sensing should ideally initiated and coordinated by the eNodeB and supported by MDs according to their capability class especially for multi-RAT measurements. Keeping unnecessary signaling overhead in mind, mechanisms of automatic MD neighborhood dedection fuzzy logic based classification of observed signals, self learning on location specific radio environments patterns and distributed consensus building are very important to reduce the regular information flow towards the network low. MD aided location and measurement time awareness may facilitate data fusion at the network side significantly, especially when TDD operation is considered and several eNodeBs supporting many MDs distributed over a larger area are involved and eNodeB synchronization, timing advance control etc become an issue.

A further important issue might be coordination of band allocation or utilization in the case of TVWS. Opportunistic TVWS usage involving additional eNodeBs in order to off-load traffic from congested licenced cellular bands must be accompanied by smart TVWS band allocation/sharing strategies. Since the activation and utilization of some or many bands in TVWS may change locally over time, this correspondes to a kind of changing infrastructure of active network elements in a particular band.

Furthermore, emerging aspects regarding **low power architectures** is highly relevant to the SDR aspects of ETSI RRS. In this sense, future topics are expected to be defined related to the overall SDR architecture design with the objective to optimise the system wide power consumption, the design and definition of interfaces which will allow access to SDR processing parameters and facilitate a real-time adaptation of power saving mechanisms to the current working state of reconfigurable devices [13]. Moreover, the innovative paradigm of **self-growing** and related mechanisms [13] could impact ETSI RRS and in particular the Cognitive Radio related working groups.

As a conclusion it can be stated that ETSI RRS is gaining broad support in the area of Next Generation Cognitive Radio Networks. An industry consensus is elaborated facilitating the fast implementation of new concepts for more efficient and flexible use of scarce spectrum resources.

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