ETSI Reconfigurable Radio System – System Aspects and Control Channels for Cognitive Radio

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Abstract—**This paper introduces novel results in the area of Cognitive Radio System (CRS) aspects and Control Channels for Cognitive Information Sharing as they are currently elaborated in the framework of the ETSI Reconfigurable Radio Systems (RRS) Technical Body. An overview of the most relevant scenarios for CRS employing opportunistic spectrum usage in the TV White Spaces is given as well as an analysis of inherently required context information provisioning solutions. Finally, an overview on the related regulatory activities and future regulatory challenges are indicated with an emphasis on expected per-device certification mechanisms which will finally enable the introduction of "*RadioApps*", i.e. software components provided to Mobile Devices (MD) which will affect the compliance of MDs to the essential requirements of the R&TTE Directive in Europe.**

Keywords-component; cognitive radio; TV white spaces; secondary spectrum access; cognitive control channels

I. INTRODUCTION

The European Telecommunications Standards Institute (ETSI) is an independent, non-profit organization, whose mission is to produce globally applicable standards for Information & Communications Technologies including fixed, mobile, radio, broadcast, internet and several other areas. Standards and Technical Specifications such as GSM™, DECT™, TETRA and DVB are prime examples of the role ETSI plays in Europe and globally. ETSI has several technical committees (TC), including the ETSI TC on Reconfigurable Radio Systems (ETSI TC RRS) which is responsible within ETSI for the standardization of Reconfigurable Radio Systems, including Software Defined Radio (SDR) and Cognitive Radio (CR) / Cognitive Radio Systems (CRS). Furthermore, ETSI TC RRS addresses pre-standardization with studies on possible to-be-standardized solutions.

TC RRS is performing work that is complementary to the IEEE DySPAN, IEEE 802 activities and IETF PAWS, with a focus on the following: i) SDR standards beyond the IEEE scope, ii) CR/SDR standards addressing the specific needs of the European Regulatory Framework and iii) CR/SDR TV White Space standards adapted to the digital TV signal characteristics in Europe.

TC RRS is building on the following Working Group structure:

- **WG1** focuses on "**System Aspects**" and develops proposals from a system aspects point of view for a common framework in TC RRS;
- **WG2** focuses on SDR technology with a particular interest in "**Radio Equipment Architecture**" and proposes common reference architectures for CR/SDR radio equipments;
- **WG3** focuses on "**Cognitive Management and Control**"; the group addresses functionalities for Reconfigurable Radio Systems which are related to the Spectrum Management and Joint Radio Resource Management across heterogeneous access technologies;
- **WG4** focuses on "**Public Safety**" and collects and defines the related RRS requirements from relevant stakeholders in the Public Safety and Defense domain.

Building on this structure, TC RRS complements ongoing effort in other bodies, by proposing technological concepts and solutions beyond the current state-of-art, and thus impacting on the future of wireless communication. As an example, TC RRS cognitive radio system and control channel concepts are considered in ITU-R work on Cognitive radio systems in the land mobile service.

TC RRS current main activities includes Reconfigurable Radio Systems operating in White Space Frequency Bands, Reconfigurable Radio Systems operating in IMT bands and GSM bands, Radio Frequency performances for Cognitive Radio Systems, Control Channels for Cognitive Radio Systems, Baseband interfaces for unified radio applications of mobile device (MD), CR/SDR for Public Safety, Security for SDR and CR based systems and Digital and Dynamic Certification.

Finally, TC RRS fulfills a key role in the framework of European Regulation in implementing ETSI Harmonised Standards required as a reference for compliance with the essential requirements of the R&TTE Directive.

The sequel of this paper is organized as follows. Section II highlights key scenarios exploiting TV White Spaces as discussed in ETSI RRS. Inherently required control channels are then introduced in Section III including indications on possible implementation solutions. The related evolution of the existing regulatory framework and corresponding future requirements are discussed in Section IV, followed by a conclusion in Section V.

II. Scenarions for using White Spaces

White space is locally unused spectrum in a band which is dedicated for a specific purpose. Authorities in different countries are planning to enable white space devices (WSD) to operate on the TV band white spaces (TVWS). The FCC ruling [1] and CEPT plans [2] propose TVWS spectrum use to be free and unlicensed for WSDs. The requirement for WSD operation is the ability to determine the locally available channels. The WSD may determine available channels by querying from a geo-location database or by spectrum sensing.

Unlicensed spectrum access allows any WSD to operate on the locally available spectrum. The scenarios introduced in this section focus on unlicensed use of TVWS. However, an alternative approach for sharing the white spaces on some other spectrum bands may be based on Licensed Shared Access (LSA) [3]. In such approach, the white spaces may be authorized for a specific secondary user. As an example a spectrum manager may be responsible for sharing access to the white spaces. This approach may enable spectrum trading and also avoiding the coexistence problems between different WSD users. Thus, LSA may be applicable for services requiring guaranteed channel access, e.g. public safety, or technologies which are designed for licensed spectrum use. Use cases for TV white spaces

ETSI RRS has defined a set of potential use cases for TVWS operation [4]. The use cases assume the unlicensed, spectrum commons approach for the white spaces use. Many existing use scenarios would benefit from the good propagation characteristics in the TV band. However, sharing the band with incumbent users and other secondary users causes some challenges.

1) *Mid/Long-range wireless access*

The mid/long-range wireless access use case describes internet access for terminals residing e.g. 0-10km distance from the base station. The base station is assumed to be at fixed location, but different mobility scenarios are considered for the terminals: no mobility, low mobility, and high mobility. As an example the terminals may be a wall-mounted home access point, a mobile terminal carried by the user while walking, or a terminal in a car or train. The scenarios are presented in **Figure 1**. The terminal mobility sets different constrains for detecting the incumbent users and affecting secondary users, as well as retrieving accurate geographical position for the terminal.

This use case assumes that the terminals support licensed technology (e.g. TD-LTE) in addition to the TVWS access technology. TVWS may be used for broadband access for example in rural areas where high data rate connections are not commonly available. Also, TVWS may be taken in use to optimize radio resource use, and on the other hand licensed band can be used for backup for retaining the connectivity when incumbent operation is detected in TVWS.

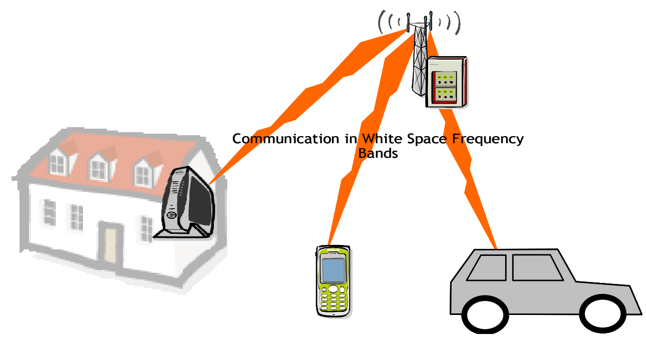

Figure 1. Mobility scenarios for WSD terminals [4].

2) *Short range wireless access*

The short-range wireless access use case describes internet access for terminals residing e.g. 0-50m distance from the access point. It is assumed that in the same geographical area there may be multiple local area networks operating in the TVWS. This use case focuses on how the white space frequency access is handled among different networks. Four different scenarios are presented for managing the coexistence between the WSD networks: no coexistence management, distributed, centralized, and hybrid of distributed and centralized coexistence management. In the first scenario the networks may use non-coordinated coexistence mechanisms, such as carrier sensing to avoid interference. In other three scenarios, the networks share information on spectrum use with other networks in more coordinated manner. The distributed management scenario assumes that all the networks are independently setup and operated, such as local area networks setup by multiple neighbors. In centralized management scenario, the frequency access for all the networks is assumed to be managed by a single entity. An example of this scenario is an office environment where all the networks are under the control of the same ownership. The hybrid scenario combines the distributed and centralized management scenario; Independent and centrally managed networks may operate on the same spectrum.

3) *Ad-hoc networking*

The ad-hoc networking use cases can be divided in pure ad-hoc scenarios and combined ad-hoc networking and wireless access scenarios. In pure ad-hoc scenarios the WSDs form device-to-device connections or ad-hoc networks for sharing information or running joint applications. Examples of such applications may be local social networking and control information sharing in machine-to-machine communication. In combined ad-hoc networking and wireless access scenarios, a node of an ad-hoc network also has an access to a base station of an infrastructure network. Both networks may operate in TVWS. The combined scenarios enable expanding the coverage of an infrastructure network using relay nodes, managing infrastructure network load, and forming infrastructure managed device-to-device links.

4) White space opportunities for cellular networking

The operation in TVWS may provide opportunities for cellular networks: the cell coverage may be expanded, and spectral efficiency may be increased by operating in TVWS. The cellular networks may enable carrier aggregation between IMT bands and TVWS, they may use TVWS only in part of the links, e.g. between relays and base stations, or they may use TVWS only for some services, e.g. Multimedia Broadcast Multicast Service. The networks may utilize TVWS temporarily, i.e. on the spectrum need and availability basis, or particularly in rural areas where more TVWS is expected to be available, the networks may rely only on TVWS operation.

B. Advanced features for WSD systems

The regulations define the prerequisite for enabling secondary operation in TVWS. The requirement to determine the availability of channels for secondary operation introduces new elements and features for the spectrum access, such as geo-location databases, WSD's spectrum queries from the database, and spectrum sensing. In future those elements and capabilities may evolve and even enable new services. As an example, the geo-location database service providers may start providing additional location-based services for the querying WSDs. The current sensing techniques are not considered technically or economically feasible methods for reliable incumbent protection. However, the sensing-based methods may be enhanced with collaborative sensing or geo-location database assisted sensing.

The regulations define requirements which concern the protection of incumbent services. Thus, they define the minimum requirements for WSD operation. The additional system functions and WSD capabilities enable more efficient spectrum use in TVWS. Some of the potential and additional features for WSD operation are currently studied in ETSI RRS [5]. The additional system functions may be defined for example for enhancing the coexistence among WSDs, or for managing aggregated interference from multiple WSDs. The future WSDs may also have better adjacent channel interference characteristics and enhanced capabilities to support the e.g. the collaborative spectrum sensing.

The WSDs may have different characteristics and capabilities depending on the use case for which the WSD is targeted, and depending on the cost of the device. The regulatory framework should allow the flexibility in the WSD implementations, and encourage the development of spectrum efficient WSDs. The CEPT has considered the location specific output power for WSDs [2]; The WSD provides at least its geo-location to the geo-location database, which provides the available channels and allowed output power on those channels at WSD's geo-location. This provides a good basis for defining output power depending on WSD characteristics and capabilities. For example, more channels or higher output power may be allowed for WSDs which cause only limited adjacent channel interference. The more the WSD is able to provide information on its interference characteristics, e.g. antenna height, direction, and angle, or whether the WSD resides indoors or outdoors, the better the geo-location database can estimate the WSD caused interference. Thus, the database may provide more accurate information on allowed parameters for the WSD which has provided additional information.

III. CONTROL CHANNELS FOR COGNITIVE RADIO

A. Concept and motivation

In today`s heterogeneous radio environment with more and more various technologies and radio interfaces, a crucial point is the coordination and radio resource optimization between different networks and nodes. Control Channels for Cognitive Radio (CCC) are designed for the information exchange between networks and nodes in order to support the coordination and coexistence management as well as radio resource optimization.

B. Technical scenarios

1) Coexistence and coordination of different cognitive radio networks and nodes

Different radio networks operating e.g. in unlicensed bands like the ISM bands or as secondary users in TV white spaces are typically uncoordinated and may interfere with each other which then leads to QoS degradation. Situations where different radio networks use the same frequency bands can be improved by exchanging information on radio resource usage or sensing results via CCC. Based on the exchanged information, the networks improve the decisions on which frequencies to use. In a further step, networks may also negotiate with each other on the spectrum usage. CCC can be used between terminals as well as between terminals and infrastructure networks.

2) Support of secondary spectrum usage

In the case of secondary spectrum usage e.g. in TVWS, the CCC can in addition to the previous scenario also be used to retrieve information from a geo-location database in order to protect primary users according the regulatory framework.

3) Single-operator multi-band multi-RAT resource optimisation

Operators operating multiple radio access technologies (RATs) in different bands (e.g. licensed IMT-bands) can improve the QoS in the network by balancing the resources between the different RATs. In such a scenario, the CCC can be used to provide terminals with context and policy information in order to efficiently discover and select available access networks.

4) Start-up information provisioning in an unknown environment

In a future scenario with flexible spectrum management where the spectrum allocated to different RATs may change dynamically within a range of different frequencies, a CCC can be used to deliver information on available operators, frequency bands and RATs at the current location of a terminal.

Such information is especially useful when a terminal starts up in new or unknown environment in order to avoid a time and energy consuming sensing of a large part of the spectrum. In such a scenario, a special flavor of a CCC, namely the out-band Cognitive Pilot Channel (CPC)[6] is seen as advantageous.

5) Opportunistic network management

Opportunistic networks (ONs) can be seen as operator-governed, temporary extensions of the infrastructure. These ONs can be used to extend the coverage of an infrastructure network, the capacity of an infrastructure network or for infrastructure supported ad-hoc networking. CCC is used in such an ON for the communication between the nodes for the suitability determination, creation, modification and termination of an ON [14].

C. Implementation options

1) Radio Access Technology independent implementation options

a) IEEE 802.21 is a standard on Media Independent Handover (MIH) Services [10] which is easily extensible to allow additional context informaton transfer. 802.21 allows different transport options including L2-based transport and IP-based transport. An advantage is that MIH information can also be included in beacons to allow information exchange even before a user is authenticated to the network.

b) IEEE 1900.4 [7] defines an architecture for distributed decision making in a heterogeneous radio environment and includes an information model describing policies, terminals and composite wireless networks. 1900.4 does not specify transport mechanisms but likely IP-based mechanisms can be used.

c) 3GPP ANDSF. The 3GPP Access Network Discovery and Selection Function [12] provides policies and access network specific information from the network to terminals to support intersystem mobility between 3GPP-networks (GSM, UMTS, LTE) and non-3GPP networks (e.g. WLAN,WiMAX). The ANDSF is network operator controlled, therefore this option is of limited use for operator-less networks like ad-hoc networks.

d) IETF Diameter [13] provides an Authentication, Authorization and Accounting (AAA) Framework, is easily extensible and is also used in 3GPP-based networks, e.g. inside the IP Multimedia Subsystem (IMS). Due to the use of IP-based transport, Diameter can only be used when a connection is established.

e) IETF PAWS defines protocols to access White Space Databases. The intention is to define database service provider independent mechanisms for any WSD to discover a white space database, the method for accessing a white space database, and the query/response formats for interacting with a white space database.

2) Radio Access Technology dependent implementation options

a) 3GPP RRC [11] enhancements can be used to distribute Cognitve Control Information in 3GPP-based systems in both idle and connected state.

b) IEEE 802.11 [8] can also be used to distribute Cognitive Control Information, e.g. by defining Vendor Specific Information elements (VSIE) or by using the Generic Advertisment Service (GAS) as described in IEEE 802.11u "Interworking with external networks"[9].

Similar extensions for sharing Cognitive Control information locally are also possible in other local and personal area technologies like Ultra-Wideband (UWB) and Bluetooth.

3) Assessment of the implementation options

The different implementation options have different advantages and drawbacks. The radio access technology independent options are very generic and can be used with any RAT but a certain type of connectivity is needed, e.g. authentication and IP Address assignment may be needed before the data exchange. RAT dependent options are low-latency solutions with low signaling overhead and they can exchange information even before a connection is established, e.g. via broadcast mechanisms.

It is expected that real deployments will use a combination of these options. Such a hybrid solution can exchange a first part of Cognitive Control Information via RAT specific mechanism before a connection is established and distribute a larger amount of information via RAT independent mechanisms after a connection is established.

IV. Required Regulatory Framework and Certification For Cognitive Radio Systems

In the regulatory framework, it has been under discussion for a number of years whether specific regulatory changes need to be introduced in order to enable the introduction of CR technology into the market. In this context, the various flavors of CR need to be considered. Considering opportunistic spectrum access in TVWS, it is broadly expected that regulatory changes will be required and implemented; in Europe, CEPT SE43 is currently studying suitable approaches and a first report has been published [2]. Taking the CR approach from a more general angle, it is discussed - in particular on the World Radio Conference (WRC) level - whether selected bands need to be reserved for CRS, for example in order to enable the introduction of a Cognitive Pilot Channel on a globally harmonized frequency band. Following the preparation discussions for WRC'2012, however, it is expected that no such CR specific bands will be allocated at this point in time (which motivates research for so-called in-band context information provision as detailed in section III.C of this paper). It is the stated position of a majority of regulation administrations world-wide that the generic CR technology does not require regulatory changes at the present time. With this decision in mind, it will still be a challenge to adapt the behavior of CR capable devices and network nodes to the existing regulatory framework.

A key requirement for CR capable mobile devices relates to an increased level of flexibility, such that they can easily adapt to a rich heterogeneous radio environment, including for example the simultaneous operation of multiple links to TVWS systems, cellular systems, metropolitan area systems and short range systems. On a European regulatory level, this requirement has been identified and the basic regulatory framework for wireless devices in Europe (the so-called R&TTE Directive - *Radio equipment and Telecommunications Terminal Equipment*) is currently undergoing corresponding changes. A revision of the existing Directive [15] is expected to be in force by 2014/2015, which will finally allow for MDs whose radio characteristics can be modified by download of specific SW components which the authors of this paper choose to call "*RadioApps*". The latter are SW components to be acquired and installed by a MD user and they affect the compliance of the MD to the essential requirements of the R&TTE Directive. The introduction of such "*RadioApps*" is indeed not possible under the existing Directive [15].

A key requirement towards those "*RadioApps*" is expected to relate to dynamic certification mechanisms as they are currently developed in the ETSI RRS Technical Body. Existing mass-upgrade mechanisms as illustrated in **Figure 2** are expected to be insufficient. Indeed, users will acquire and install a multitude of "*RadioApps*" which may undergo different installation orders, simultaneous execution, etc. Consequently, a per-device certification approach is likely to be required as indicated by **Figure 3**. A more detailed presentation of possible solutions is available in [16].

To summarize, it is expected that CR regulatory activities in the near future will mainly focus on opportunistic spectrum/TVWS usage and requirements related to the revision of the R&TTE Directive.

V. CONCLUSIONS

This paper presented ETSI TC RRS scope and activities related to Cognitive Radio System (CRS) aspects and Control Channels for cognitive information sharing. An overview of the defined scenarios for TVWS white spaces use and potential advanced features for WSD systems is given. Technical scenarios and various implementation options for the Control Channels for sharing cognitive information are introduced. Finally, the related evolution of the existing regulatory framework, as well as corresponding future requirements and challenges are discussed.

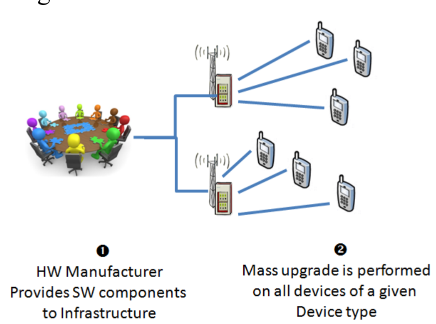

Figure 2. Existing regulatory regime, e.g. FOTA Mass-Upgrades.

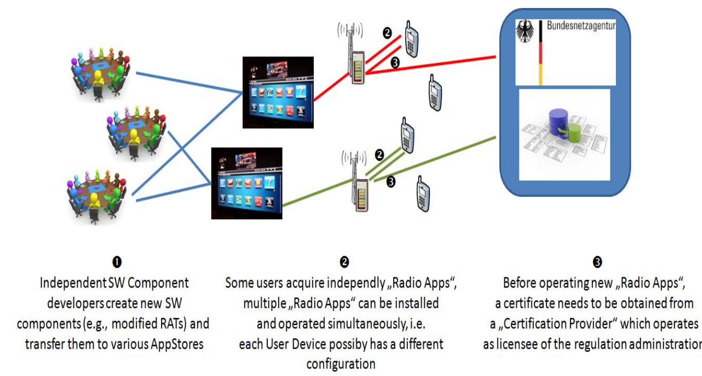

Figure 3. Expected regulatory regime building on Dynamic Certification.

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