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Contents

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Foreword

This Technical Report (TR) has been produced by ETSI Technical Committee Reconfigurable Radio Systems (RRS).

Introduction

The present document provides a feasibility study on reconfigurable radio systems which are capable to use technological elements known as Cognitive Radio. An overall and harmonized technical concept for future Cognitive Radio Systems is outlined.

There are several factors driving the future evolution of radio technologies and network architectures towards more flexible and reconfigurable Cognitive Radio Systems:

Increasing growth of mobile traffic in terms of subscribers, data volumes and data rates

There are more than 3 billion mobile phone users today. There are estimations (e.g. by WWRF) that by 2017 there will be 7 trillion wireless devices serving 7 billion users. To meet these expectations with the limited amount of radio spectrum, more flexible ways to exploit the radio frequencies among multiple services and radio networks are needed.

Multitude of standards, Composite wireless networks and multiradio terminals

Many communication applications, which originated as tightly-coupled with specific radio technologies, would benefit from decoupling the application from the radio platform. At the same time network operators are building composite wireless networks to provide access to multiple services. When a multiradio terminal is having multiple applications simultaneously active, there is a need to coordinate the operations of the different radios in order to reach the cost and energy efficient use of overall radio communications capacity.

Regulators are starting to consider the extension of the possibility to allow secondary access to some frequency bands, increasing spectrum utilization

In order to meet the increasing data traffic volumes regulators have started to consider the extension of the possibility to allow wireless data devices to operate as secondary users on spectrum bands which traditionally have been dedicated to their primary users alone. In the case, this sets new requirements to future radio technologies to deal with this possible scenario. In November 2008 the US FCC issued a report and order which adopts rules to allow unlicensed "white space" devices to operate in the broadcast television spectrum at locations where that spectrum is not being used by licensed primary users.

1 Scope

The present document provides the objectives and properties for and formulates an overall and harmonized technical concept for Cognitive Radio Systems. Both infrastructure as well as infrastructure-less radio networks will be covered. The main scope of the present document is to illustrate how the reconfigurability and cognition functionalities can be introduced in the future radio networks both on the terminal and network sides. Based on such system concept and requirements the identification of candidate topics for standardization at ETSI concludes this study. The feasibility study includes also a survey of related activities in other standardization bodies.

2 References

References are either specific (identified by date of publication and/or edition number or version number) or non-specific.

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2.1 Normative references

The following referenced documents are indispensable for the application of the present document. For dated references, only the edition cited applies. For non-specific references, the latest edition of the referenced document (including any amendments) applies.

Not applicable.

2.2 Informative references

The following referenced documents are not essential to the use of the present document but they assist the user with regard to a particular subject area**.** For non-specific references, the latest version of the referenced document (including any amendments) applies.

[i.1] ETSI TR 102 838: "Reconfigurable Radio Systems (RRS); summary of feasibility studies and potential standardization topics".

[i.2] ETSI TR 102 680: "Reconfigurable Radio Systems (RRS); SDR Reference Architecture for Mobile Device".

[i.3] ETSI TR 102 682: "Reconfigurable Radio Systems (RRS); Functional Architecture (FA) for the Management and Control of Reconfigurable Radio Systems".

[i.4] ETSI TR 102 683: "Reconfigurable Radio Systems (RRS); Cognitive Pilot Channel (CPC)".

[i.5] IEEE Std 1900.4-2009: "IEEE Standard for Architectural Building Blocks Enabling Network-Device Distributed Decision Making for Optimized Radio Resource Usage in Heterogeneous Wireless Access Networks", February 27, 2009.

[i.6] Final Draft Report RSPG09-299: "Radio Spectrum Policy Group Report on Cognitive Technologies", EU Commission DG INFSO/B4/RSPG Secretariat, Brussels, October 14, 2009.

[i.7] E3 Deliverable D4.5: "Final system specification for autonomous CR functions", December 2009.

[i.8] E3 Deliverable D3.3: "Simulation based recommendations for DSA and self-management", July 2009.

[i.9] IEEE P802.22 D2.0: "Draft Standard for Wireless Regional Area Networks Part 22: Cognitive Wireless RAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: Policies and procedures for operation in the TV Bands", May 2009.

[i.10] IEEE 802.22-09/0159r10: "PAR modification for portable CPEs", November 2009.

[i.11] IEEE 802.11-09/0934r8: "TVWS PAR and 5C", November 2009.

[i.12] IEEE Std 802.21-2008: "IEEE Standard for Local and metropolitan area networks - Part 21: Media Independent Handover Services", January 2009.

[i.13] IEEE P802.22.1: "PAR, Standard to enhance harmful interference protection for low power licensed devices operating in TV Broadcast Bands", March 2006.

[i.14] IEEE P802.19-09/0078r5: "TVWS Coexistence PAR", November 2009.

[i.15] Working Document towards Draft CPM Text on WRC-12 Agenda Item 1.19, September 2009.

[i.16] Cognitive radio systems in the land mobile service, Working Document towards a Preliminary Draft New Report ITU-R [LMS.CRS], Annex 15 to Document 5A/305-E, June 2009.

3 Definitions and abbreviations

3.1 Definitions

For the purposes of the present document, the following terms and definitions apply:

cognitive radio system: radio system employing technology that allows the system to obtain knowledge of its operational and geographical environment, established policies and its internal state; to dynamically and autonomously adjust its operational parameters and protocols according to its obtained knowledge in order to achieve predefined objectives; and to learn from the results obtained

NOTE: This is the current definition of ITU-R Recommendation WP 1B.

cognitive control network: network of nodes in different cognitive radio networks communicating with each other for controlling the frequency agile behaviour among the set of cognitive radio networks

cognitive control channel: logical channel between nodes belonging to a same cognitive control network

cognitive control radio: radio (technology) designed to carry cognitivity control information between cognitive control network nodes

cognitive pilot channel: channel which conveys the elements of necessary information facilitating the operations of Cognitive Radio Systems

radio technology: technology for wireless transmission and/or reception of electromagnetic radiation for information transfer

NOTE: Radio technology is typically designed to use certain radio frequency band(s) and it includes agreed schemes for multiple access, modulation, channel and data coding as well as control protocols for all radio layers needed to maintain logical links for user data, which run the same radio application.

radio equipment: equipment using radio technology

radio network: network of radio equipments communicating with each other by using a common radio technology

NOTE: Typically a radio network has both control plane and user plane with their own protocols. A radio network may also be subject to radio network management by an external network management system; in this case a third plane of protocols, management plane is used for communicating network management information.

software defined radio: radio transmitter and/or receiver employing a technology that allows the RF operating parameters including, but not limited to, frequency range, modulation type, or output power to be set or altered by software, excluding changes to operating parameters which occur during the normal pre-installed and predetermined operation of a radio according to a system specification or standard

NOTE: This is the current definition of ITU-R Recommendation WP 1B.

software defined multiradio: device or technology where multiple radio technologies can coexist and share their wireless transmission and/or reception capabilities, including but not limited to regulated parameters, by operating them under a common software system

NOTE 1: Examples of the regulated parameters are frequency range, modulation type and output power.

NOTE 2: Common software system represents radio operating system functions.

NOTE 3: This definition does not restrict the way software is used to set and/or change the parameters. In one example, this can be done by the algorithm of the already running software. In another example, software downloading may be required.

spectrum sensing: act of measuring information indicative of spectrum occupancy

NOTE 1: Information may include frequency ranges, signal power levels, bandwidth, etc.

NOTE 2: Spectrum sensing may include obtaining additional information on how the sensed spectrum is used.

3.2 Abbreviations

For the purposes of the present document, the following abbreviations apply:

AFA	Adaptive Frequency Agility
AP	Access Point
BB	baseband
BS	Base Station
BTS	Base Transceiver Station
C-NMS	Cognitive Network Management System
CCN	Cognitive Control Network
CCR	Cognitive Control Radio
CMN	Cognitive Mesh Network
CR	Cognitive Radio
CRS	Cognitive Radio System
CWN	Composite Wireless Network
DAA	Detect And Avoid
DFS	Dynamic Frequency Selection
GSM	Global System for Mobile communications (originally Groupe Spécial Mobile)
HPR	Hardware Processing Resources
JRRM	Joint Radio Resource Management
LBT	Listen Before Talk
LTE	Long Term Evolution
MAC	Medium Access Control
MUE	Multiradio User Equipment
NBAP	NodeB Application Part (protocol)
O&M	Operation and Maintenance
OSM	Operator Spectrum Manager
PHY	Physical layer
QoS	Quality of Service
RAT	Radio Access Technology

RF	Radio Frequency
R-RBS	Reconfigurable Radio Base Station
RRM	Radio Resource Management
RRS	Reconfigurable Radio Systems
UE	User Equipment
UHF	Ultra High Frequency
UMTS	Universal Mobile Telecommunications System
UWB	Ultra Wide Band
WLAN	Wireless Local Area Network
WRC	World Radio Conference

4 Objectives and Requirements for CR Systems

4.1 Objectives of the CR Systems

Cognitive Radio Systems are expected to increase the efficiency of the overall spectrum usage by offering new sharing opportunities and also to provide more flexibility to applications as a result of their ability to adapt their operations to external and internal factors.

The new sharing possibilities can facilitate access to new spectrum bands and the increased flexibility to applications can improve the cost efficiency and capabilities to deliver various services as well as better take into account the users' needs.

Cognitive Radio Systems are also expected to increase the efficiency and flexibility of the radio resource management within mobile operator networks as a result of their ability to adapt their operations to external and internal factors.

4.1.1 More efficient and flexible use of spectrum

In practice, not all frequencies are in use full time. CRSs are able to identify the unused portions of spectrum and share that spectrum without interfering with the existing users harmfully. Furthermore, the usage of the spectrum may vary over the time and over different locations and in such case CRS can improve the efficiency and flexibility of spectrum usage utilising the envisaged CR capabilities.

For this purpose, the CR Systems need to perform three key activities:

1) obtain knowledge of the radio operational environment and location;

2) decide on the gathered information; and

3) act based on this decision.

This kind of new way of spectrum utilization is expected to increase the capacity of the networks, allow access to new spectrum bands and also increase the economic value of spectrum.

4.1.2 Enhancing User Experience

Enhancing user experience is one of the main objectives of the CRS. A user of a radio system is interested in receiving high quality seamless service. From this perspective the CRS can enhance user experience.

This can be applied to the following situations:

1) **Cross-Operator Access:** A user may have several subscriptions to different services provided by different operators. Also, the user can have different preferences, for example, short download time, stable connection, low cost. By analyzing user preferences and user environment, the CRS can allow user to connect its terminal to the wireless access network that best fits his/her current preferences.

2) **User Network:** A user may have different devices in his/her flat that need to be connected to each other and/or to Internet. For convenient connection different types of devices may have different requirements, e.g. high bandwidth, low power consumption, etc. By selecting appropriate operations parameters and protocols, the CRS can provide the connection that best fits types of devices that user owns.

3) **Flexible Access to the Future Internet:** As it is currently the case also future systems will continue to provide network access as their main service. Future Internet access requires new and innovative ways to access the network, route data flows to their destination, and access information. Further the amount of required information is steadily increasing resulting in needs for higher data rates and improved spectrum utilization.

4) **Connecting the smart spaces:** Next to accessing a central network, in the future more and more devices will be interconnected wirelessly, resulting in the need for fast device discovery, agile use of the spectrum to facilitate ad-hoc interactions between devices and long life-times of networks under uncertain connectivity circumstances.

4.1.3 Optimization of the mobile operator network

The challenge from operator perspective is to answer user needs in a timely and adapted manner satisfying the requirements in terms of Capacity (throughputs) and QoS. Cognitive Radio system having the potential to obtain information from the radio eco-system and analyse the radio operational environment can make the operator's network react accordingly by optimizing the choice of radio access technologies and associated radio resources (always optimized connected approach).

This can be applied to assist the optimization of the mobile operator network the following situations:

1) **Load balancing**

When load balancing mechanism is part of the optimization process in case of traffic variations in space/time or nature of required service/application. Uplink traffic demand information from UE and/or dedicated sensors can trigger the needed reconfiguration of the Multiradio elements both in the network and user multimode terminals.

2) **Spectrum refarming**

A particular situation is that of spectrum refarming in the context of technology evolution and periodical emergence of new families of standards. This implies their progressive introduction/coexistence in the legacy "bands" rather than a simple and quick switchover which is not appropriate due to the large amount of legacy equipment and the corresponding investments. CR system can allow a smooth refarming transition period in this case taking into account the traffic constraints and user requirements.

3) **RRM optimization**

Considering a cell set in a certain area, the traffic of different services on a specified RAT may change from one sub-area to the other according to the day period. Moreover it could happen that some cells may be congested (high blocking percentages) in some particular area (typically these portions are called hot-spots) in which the traffic is more consistent, while surrounding cells are less loaded or characterized by low blocking percentages. Moreover, in case of deployment of two or more RATs in the same area, the offered traffic of different services on each deployed RAT may also be differently distributed in time and space with respect to the ones of the other deployed RATs. In such contexts, in the longer term, CRS will give the network operators the means for managing in an efficient way the radio resources within its own licensed frequency bands.

4) **Cognition Enabler**

Considering an heterogeneous or multi-RAT context in which Dynamic Spectrum Allocation schemes could be performed, the mobile terminal will need to initiate a communication in a spectrum context which is mostly unknown due to such dynamic allocation mechanisms, without requiring an excessive complexity. Efficient mechanisms to provide the sufficient information to the terminals for initiating a communication session appropriately are then needed.

5) Decentralized RRM

Contexts in which the system complexity can be relaxed by moving part of the radio resource management functionality into more decentralized solutions, requires solutions for enabling such network-assisted decentralized radio resource management. Context information (e.g. network radio capabilities, network/mobile measurements, geo-location information, etc.), network policies and other kind of information (e.g. operative software to reconfigure the terminal or advertising or road/car traffic information) have to be efficiently provided to the interested devices.

4.1.4 Other Objectives of CR Systems

In the longer term cognitive radio technologies may play a fundamental role in the shift from static spectrum management to dynamic spectrum management and access. This longer term goal has been recognized also by the EU Commission Radio Spectrum Policy Group [i.6].

4.2 Spectrum Use Scenarios for CRS

In this clause different spectrum use scenarios for cognitive radio systems are considered. Each of the scenarios is also categorized as a short-term, mid-term or long-term scenario based on the technological and regulatory evolution expected to realize the scenario.

There are four different classes of radio spectrum use scenarios for the Cognitive Radio Systems described in the present document:

- Dedicated spectrum (licensed bands).
- Shared spectrum (license-exempt bands).
- Secondary usage in dedicated spectrum.
- Spectrum dedicated for CRS.

The rest of this clause describes these spectrum use scenarios for cognitive radio systems in more detail.

4.2.1 Dedicated spectrum (licensed bands)

In this scenario the reconfigurability is introduced in the currently licensed bands.

Scenario L.1: Software defined multiradio in (end-user) mobile devices (short-term)

This first scenario assumes that software defined multiradio technology is used to realize reconfigurability of radio equipments in mobile devices (end-user terminals). A reconfigurable radio is capable to scan the radio frequencies and make an autonomous selection of radio (access) technology based on user preferences.

This scenario is covered by TR 102 680 [i.2].

Scenario L.2: Radio (access) technology selection in composite wireless networks (short-term)

In this scenario an operator is utilizing multiple radio (access) networks on different frequency bands as assigned to them under the current regulation and wants to combine these radio networks into a single composite wireless network. Similarly the subscriber devices are equipped with software defined multiradio capability in order to operate on multiple radio networks. By monitoring the traffic load on different radio networks the cognitive network management system can decide on the assignment of users to different radio (access) technologies in a dynamic manner, which leads to optimal use of the composite capacity of the frequency bands. This scenario is also applicable to a situation where the radio networks are not owned by a single operator but where several operators cooperate to manage their composite radio networks jointly.

This scenario is covered by TR 102 682 [i.3].