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Reconfigurable Radio Systems (RRS); Cognitive Radio System Concept

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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].

Scenario L.3: Radio resource usage optimization in composite wireless networks (short-term)

In this scenario one or several operators operate multiple radio access networks on different frequency bands assigned to them. Network side radio nodes of these radio access networks have reconfiguration capability implemented, for example, using software defined radio technology. Similarly terminal side radio nodes also have reconfiguration capability. Reconfigurable radio nodes on network side dynamically adjust their operational parameters and/or radio resources in order to meet some predefined objectives (e.g. increase capacity and improve QoS) and according to the current radio regulations. Such adjustment can include changing operating frequency band and radio access technology. Following network reconfiguration, terminals may need to reconfigure.

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

4.2.2 Shared Spectrum in bands without primary users

Scenario U.1: Cognitive radio networks on unlicensed bands (short-term)

In this scenario cognitive radio networks are deployed in bands that do not require licensing (license exempt bands). There is only one class of users sharing such a band. This potentially provides for easy deployment of cognitive radio systems. There is an opportunity of sharing spectrum resources in these bands. This is already applied today, for example collaboration between Bluetooth and WLAN in the 2,4 GHz band and more generally speaking most of the ISM bands.

There are restrictions to the use of unlicensed bands in terms of transmit power and/or power density for instance that do not allow such an approach to be used for wider areas. Further the amount of unlicensed spectrum is limited and especially at the 2,4 GHz WLAN already heavily used.

4.2.3 Secondary usage in bands with primary users

Scenario S.1: Exploit spectrum opportunities in bands already assigned to primary users (mid-term)

In this scenario cognitive radio networks share, on a secondary basis, one band or several different bands assigned to one (or several) primary user(s). Before accessing the spectrum the nodes should obtain information about the spectrum, which is available for secondary usage on their particular location. Nodes have to have means how the cognitive networks can avoid causing harmful interference to primary networks and co-exists with each others. This approach results in a more efficient usage of the spectrum in selected band provided that there is no harmful interference to the already deployed systems.

For example Dynamic Frequency Selection (DFS) for WLAN in 5 GHz band, to avoid interference to military and meteorological radars, is a first step towards such secondary usage.

4.2.4 Spectrum dedicated for CRS

Scenario C.1: Specific band allocated for cognitive use (long-term)

In this scenario a specific dedicated band is assigned for a service utilizing cognitive radios. All radio technologies accessing this band are designed to meet specific interference targets, and are aware of the interference that may be caused by competing system. This means that the sharing of the spectrum resources in the band can be implemented in a very efficient manner.

4.3 Technical Requirements on CR Systems

This clause introduces some key requirements for the Cognitive Radio Systems. Technical solutions to meet these requirements are needed to provide cognitive radio services for mobile users. The enabling technology elements, on which such technical solutions are dependent, are also mentioned for each requirement presented below.

R-I Scalability and Insensitivity to Network Topology Changes

The cognitive radio networks scale well with the number of users/nodes in the networks. The network can be established with only two network nodes and scales gracefully with the number of nodes and area of the network. The cognitive radio network reacts gracefully and is robust to changes in network topology. Links may disappear because of agile spectrum conditions, and nodes may leave the network, for instance because of user mobility or powering off devices. Connectivity between the network nodes should be maintained in a robust manner, and advanced protocols are required that reconnect nodes via different frequency bands.

Enablers: Efficient routing algorithms, Dynamic distributed radio resource allocation, Distributed algorithms, Self healing techniques, Self-organisation

R-II Power Efficiency

The power consumption of the CRS design allows long standby, monitoring and active times. As a whole this requirement is expected to be met by each network node when taking also into account the new functions like relaying, collaboration and cooperative spectrum sensing.

Enablers: Long sleep times, Multiple operational states, Cognitive control channels with efficient protocols.

R-III Network and Service Discovery

The CRS provides the first connection to the desired service in a short time, acceptable to a customer. A user can join a network within a reasonable time. The CRS protocols are designed in such a way that the user can be informed in reasonable intervals of delays and progress of a connection/service request, if a certain deadline defined by network policies is not met.

Enablers: Network and service discovery protocols, Network policies, Fast initial access to cognitive radio network.

R-IV Robust Control Plane

The control planes both within all cognitive radio networks as well as between them should be robust and able to continue to provide connectivity in frequency agile environments.

Enablers: Robust coding, Cognitive control channels with dedicated frequency bands

R-V Reconfigurability of the Radio Equipments

The radio equipments in the cognitive radio network nodes are capable of adjusting to different radio frequency environments. This kind of frequency agility means that the transmission parameters and resource allocation can be easily adjusted to the needs of the operator and/or the user, or the interference environment in a particular band.

More in detail:

- Reconfiguration in both hardware (e.g. both BB and RF) and radio resources for each supported RAT.
- All RATs implemented (e.g. by software) in the equipment will be fully compliant with the current existing standards (e.g. GSM, UMTS, LTE, WIMAX, etc.) and related regulatory restrictions (bands, frequencies, power levels, spectrum masks).
- Support of multi-standard operations.
- The percentage of hardware/processing resources devoted to each supported RAT can be dynamically modified.
- The number of frequencies/channels assigned to each supported RAT can be dynamically modified.
- Equipment reconfiguration taking into account the experimented network and users conditions (e.g. traffic and/or interference conditions).
- Reconfigurable equipment should be able to receive and execute reconfiguration commands coming from entities that manage the reconfiguration of the network via common standardized interfaces; such entities may be located either in user devices or e.g. in access or in core network or in O&M nodes, considering also flat architectures (e.g. HSPA+ and/or LTE based).

- Reconfiguration phase will be performed in real-time and/or in the fastest way without the necessity to shut down and restart the device (e.g. in case of Multi-RAT operations/reconfigurations).

Enablers: Software defined multiradio, Frequency agility, Reconfigurable and tunable RF equipment

R-VI Context, policies and information provisioning support

For the purpose of supporting cognitive radio network nodes in their selection of radio technology and frequency band as well as radio link configuration, context provision needs to provide the radio context information such as e.g. available frequencies and radio technology selection constraints (policies).

Enablers: Spectrum database, Geo-location, Cognitive control channels, Spectrum policies

5 Technical Framework for Cognitive Radio System

This clause outlines the cognitive radio system concept. First a generic layered model for spectrum management is presented. Based on that both centralized and decentralized approaches to architecting of CR systems is described. Within those conceptual architectures we distinguish three communication planes, which may host the cognition functions. Finally some of the key enabling technology elements, which were already identified in c 4.3, are described.

5.1 Spectrum Management Layers for Cognitive Radio Systems

While increasing the flexibility and dynamic use of spectrum it is useful to refer to a commonly agreed spectrum management framework. By deriving from the overall objectives and technical elements presented in this study report the following layered structure for spectrum management for CRS can be considered.

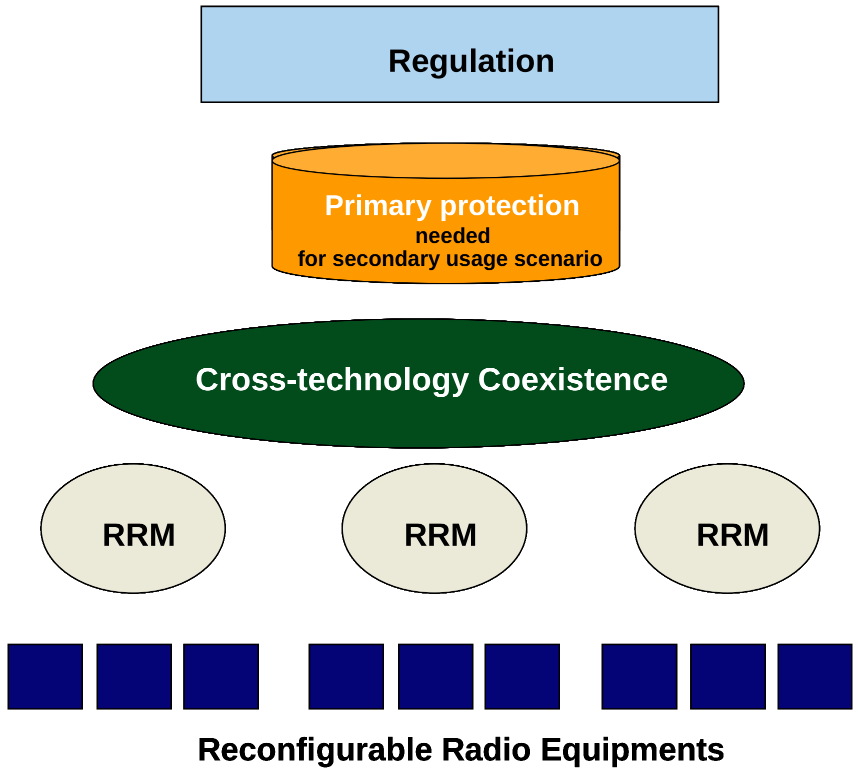

Figure 1: Spectrum Management Layers for CRS

The time span of spectrum management actions carried out by the different layers in figure 1 is decreasing when moving from the Regulation layer down towards Reconfigurable Radio Equipments. Depending on the different objectives of CR systems, not all the reported layers need to be involved.

Spectrum Regulation Layer

Due to the scarcity of radio spectrum it is foreseen that regulation will continue to play a role in assigning spectrum to different radio services. In the longer term cognitive radio technologies will play a fundamental role by accelerating the transition from medium to long term spectrum management to more dynamic spectrum management and access [i.6]. Regulation will anyway continue to play a significant role as neutral third party between the various spectrum users (scientific, governmental, aeronautical, maritime, etc.), to solve interference issues between them.

Primary protection Layer

The purpose of a Primary protection layer is to introduce protection to the primary users of the spectrum.

Cross-technology Coexistence Layer

When multiple cognitive radio technologies seek access to a common spectrum band a need for cross-technology coexistence layer become evident.

Radio Resource Management Layer

The most fine-grained and short time-span decisions on spectrum resource utilization are carried out by the RRM functions, which are specific to each cognitive radio system technology.

Reconfigurable Radio Equipments Layer

The transceiver equipments in each radio node of CR system are responsive to the RRM decisions by allowing run-time reconfiguration of multiple radio parameters along the SDR paradigm. The long-term goal for reconfigurable radios is to make the transceivers as frequency agile as possible. There are however still major challenges especially within the RF front-end components (e.g. RF filters), which need to be taken into account when designing CR system technologies.

5.2 Architectural Approaches for Cognitive Radio Systems

In the context of TC RRS studies Cognitive Radio Systems are regarded as networks having high-level structures with multiple system components as illustrated in figure 2.

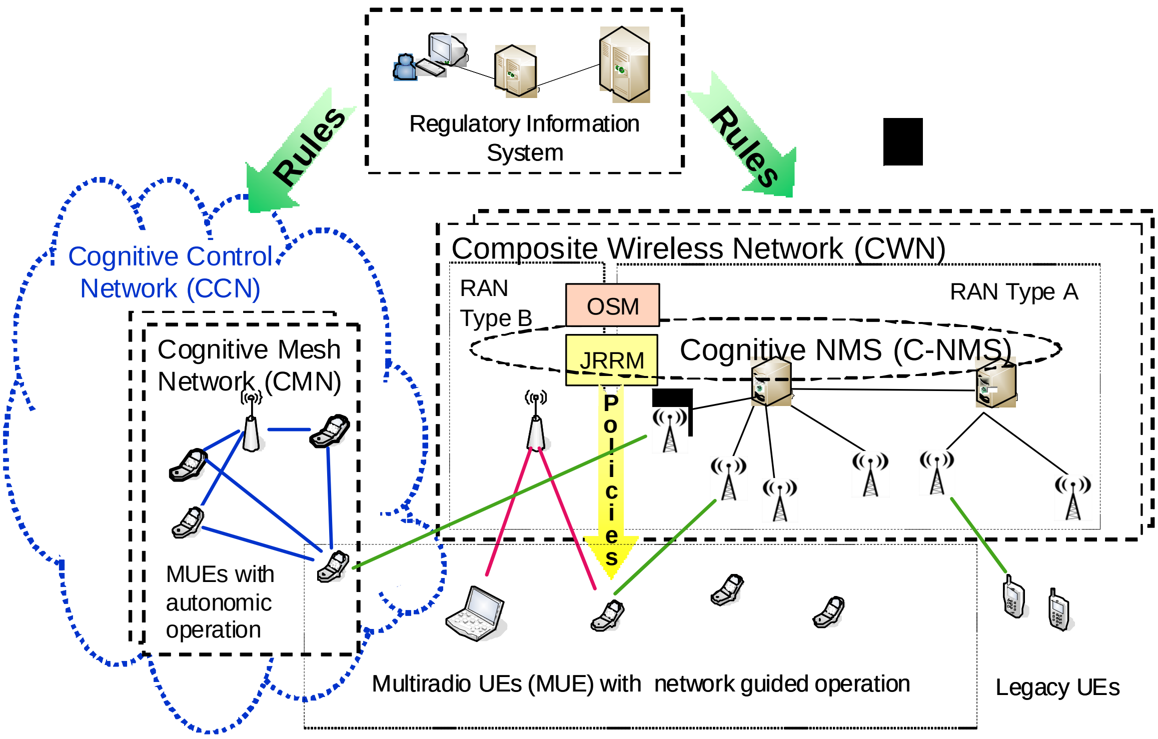

Figure 2: Centralized and decentralized CR system concepts

Figure 2 illustrates the two main approaches on how CRS features may be introduced into existing networks. In the case of a hierarchically organized and centrally managed radio access network (on the right hand side of figure 2) the radio network management system (C-NMS) is enhanced with cognitive features for controlling the reconfiguration of radio base stations and mobile devices. In the case of device only networks organized in ad-hoc manner as mesh or multi-hop mesh networks (on the left hand side of figure 2) the CRS functionality is accomplished in distributed manner as collaboration among the autonomous mobile devices and networks. The key enabler for such cognitive collaboration is the Cognitive Control Network (CCN).

Neither specific implementation architectures nor specific interfaces between the network elements in figure 2 are assumed in this high-level conceptual representation of these two approaches.

Multiradio User Equipment (MUE)

Multiradio User Equipment represents a user device, equipped with a software defined multiradio technology, which makes the radio capabilities reconfigurable. Reconfiguration may include installation and loading of new radio software applications into the user equipment or modification of radio parameters including also the radio frequency band used to carry the user traffic.

Since a MUE has multiple radios, which can be active at the same time, it may have connections to multiple radio networks at the same time. Some of those radio networks may deploy cognitive radio technology to use radio frequencies in agile manner, others may use conventional radio technologies on their native frequency bands.

Besides the ordinary user data radios a MUE may also use some radios to assist the cognitive control functions. Examples of such radios are spectrum sensing radio and geolocation radio, which can assist a cognitive user data radio to operate as a secondary user on a spectrum band, where interference to primary users need to be avoided.

Composite Wireless Network (CWN)

Composite Wireless Network represents a set of radio networks, which is operated by a network operator using a common network management system. Each radio network consists of two kinds of radio nodes: user nodes and access nodes. User nodes may be MUEs as described above. Access nodes are base stations in a general sense. Such a node may also be reconfigurable and may use software defined multiradio technology. Such access nodes are referred to as Reconfigurable Radio Base Stations (R-RBS) below.

Some of the radio networks in CWN may be cognitive. They use radio frequencies in agile manner, in which case both user nodes and access nodes deploy a common cognitive radio technology. Other radio networks may use conventional radio technologies and operate on their native frequency bands.

OSM (Operator Spectrum Manager) is an entity that enables the operator to control dynamic spectrum assignment decisions within his CWN.

JRRM (Joint Radio Resource Management) is an entity inside C-NMS that enables management of composite radio resources and selection of radio access technologies for user traffic connections.

NOTE: This description of CWN is valid even in such a case, when none of the radio networks is using cognitive radio technology.

Cognitive Network Management System (C-NMS)

An operator of a CWN aims to share the overall traffic from all MUEs across the different radio networks in a cost-effective manner. To enable this both user nodes and access nodes need to be reconfigurable under the rules from the operator's Cognitive Network Management System. Such a C-NMS represents a centralized cognitive management element, which collects traffic load and spectrum usage information from the CWN and allocates traffic to different radio networks in the CWN. In addition to such cognitive traffic management functions a C-NMS may also include a set of ordinary network management functions.

Cognitive Mesh Network (CMN)

MUEs may also use some radios, typically short-range ones, to establish ad-hoc and mesh networks among themselves to provide different kinds of social networking services. The ability to use reconfigurable and cognitive radios for carrying those services among the set of MUEs adds a lot of flexibility in getting wide variety of different MUEs connected to such Cognitive Mesh Networks (CMN).

There may be multiple CMNs active in the same area, each of them serving different group of end-users and services. By using opportunistic spectrum access in collaborative manner] the CMNs can coordinate their use of radio frequencies. Interworking between CMNs may be arranged in a decentralized manner by using logically separate Cognitive Control Network (CCN) to share information between CMNs which operating in the same geographical area and therefore need to coordinate their spectrum access.

CMNs and CWNs belong to two separate domains in terms of used radio frequencies and RATs.

MUEs can connect to both CMN and CWN. Inside CMN domain, MUEs do not act as relay entities towards CWN for others MUEs, while each of them may connect directly to CWN by the appropriate RAT, e.g. GSM, UMTS, LTE.

5.3 Communication Planes in CRS Network Elements

All network elements in the CRS networks - both in centralized and decentralized architectures described above - include functions and protocols for:

- user data transfer;
- communications control; and
- cognitive network management and control.

The feasibility studies of the TC-RRS Working Groups have elaborated different approaches into definition, specification and possible standardization of RRS network architectures and protocols for these functional planes.

Planes in MUE

Every MUE operates as a member of one or more radio networks under the supervision of the internal **control planes** of those radio networks. Control plane functions typically include the radio network specific medium access (MAC) and radio resource management (RRM) schemes. In case of cognitive radio network the internal control plane may be extended to deal with opportunistic spectrum access and frequency agility control, e.g. spectrum sensing and procedures for evacuation of the radio network from a spectrum band, which has been detected to become occupied by a primary user.

Every MUE also has a radio network specific **user plane**, which takes care of carrying the user data traffic originating and being targeted from/to applications executing in the MUE.

Besides user and control planes, a MUE also has **cognitive management plane** functions for operating as a user node in centrally managed CWN and/or for operating as an autonomous user node in one or many CMNs.

When a MUE operates as a user node in centrally managed CWN, it also includes cognitive management plane functions and protocols, which allow the C-NMS to reconfigure the radios at MUE e.g. by installing and loading new radio software applications, by (re)setting operating parameters of some radios and by loading operator-specific policy information, which is used to govern radio technology selection for user data traffic connections at MUE.

When a MUE is a member of (possibly many) CMNs, it has cognitive management plane functions and protocols for coexistence and collaboration with other CMNs operating on the same cognitive frequency bands in the same geographical area. Examples of such functionalities are network and service discovery to get initial access to the desired CMN and collaborative spectrum sensing among a set of CMNs.

Planes in R-RBS

A reconfigurable multiradio base station has **user and control planes** for each of the supported radio networks. User plane is used to carry the user data traffic and control plane is used to govern the radio network internal control of radio operations. Being part of a CWN a R-RBS also has **cognitive management plane** for composite network management procedures supervised by the network operator's C-NMS. Cognitive management plane enables load-dependent traffic sharing across multiple radio networks as well as reconfiguration of R-RBS capabilities for flexible use of available spectrum resources.

Planes in C-NMS

All functionalities of C-NMS belong to **cognitive management plane**.

5.4 Enabling Technologies for CR Systems

This clause briefly describes a number of technological building blocks which have been recognized as essential enablers for Cognitive Radio Systems. Some of them have already been studied by TC-RRS Working Groups.

Many technologies have contributed to the CRS concept. Among them are the following technologies:

- Pre-cognitive Radio Technologies
- Software Defined Radio and Multiradio
- Reconfigurable Base Stations Management
- Spectrum Sensing
- Cognitive Pilot Channel
- Cognitive Control Radio and Networking
- Geolocation
- Primary Protection Database
- Distributed Decision Making

The rest of this clause describes these enabling technologies in more detail.

5.4.1 Pre-cognitive radio technologies

Some radio applications currently available on the market already incorporate some of the features of cognitive technologies:

Dynamic Frequency Selection (DFS)

Where a transmission delay is unacceptable, a device may use Listen Before Talk (LBT) in combination with Adaptive Frequency Agility (AFA). This combination of LBT/AFA is often called Dynamic Frequency Selection (DFS). By using this method, the equipment will search for a different free channel as soon as it detects that the wanted channel is occupied. Transmission delay by this method is minimized to the listen time defined by the LBT/DFS algorithm.

Detect and Avoid (DAA)

Detect and Avoid (DAA) mechanisms are mechanisms which detect the presence of signals from other radio systems (such as fixed broadband wireless access and mobile services) and reduce the transmitted power of the UWB device down to a level where it does not cause interference to indoor reception of these systems.

These pre-cognitive systems obtain knowledge of the operational and geographical environment by sensing the radio environment. Mechanisms to react to this radio environment are embedded in the MAC and PHY layers of the radio equipment and refer to spectrum management policies on the assumption that they will not be modified during the device's lifetime.

This experience from deployment of pre-cognitive radio systems is relevant for the future development of CRSs.

5.4.2 Software Defined Radio and Multiradio

The capability to adjust operational parameters is one of the key capabilities of the CRS. In many scenarios, the radio nodes of the CRS change their operating frequency bands and RATs. While it is not mandatory, a convenient way to reconfigure radio nodes is by using Software Defined Radio (SDR) technology.

Software Defined Radio technologies for Multiradio User Equipments (MUE) have been studied in TR 102 680 [i.2].

5.4.3 Reconfigurable Base Stations Management

Considering the third objective reported in clause 4.1, the deployment of a network using reconfigurable nodes (e.g. base stations) will give the network operators the means for managing in a globally efficient way the radio and processing resource pool, with the aim to adapt the network itself to the dynamic variations of the traffic offered to the deployed RATs and to the different portions of the area.

As an example, it could be considered the deployment of RAT1 and RAT2 systems in a geographical area with a network built with reconfigurable base stations. In this kind of network, the Hardware Processing Resources (HPR) belonging to a reconfigurable base station are shared between RAT1 and RAT2 functionalities. During the daily life of the network, it could be needed, for instance due to different traffic loads on the two RATs, to increase the percentage of processing resources devoted to the over-loaded system while decreasing the resources given to the other (supposed under-loaded). In figure 3, a reconfiguration example increasing RAT2 resources is depicted.

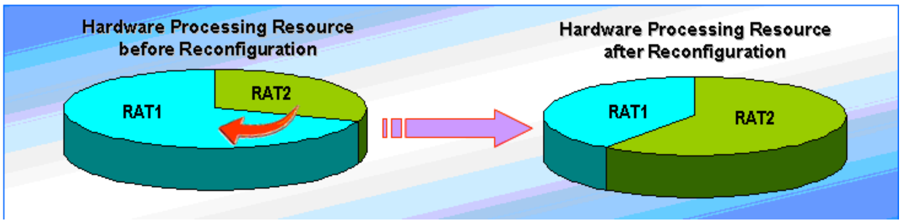

Figure 3: Hardware reconfiguration example

A possible architecture to enable the aforesaid traffic handling mechanism is reported in figure 4. Such architecture is constituted by Reconfigurable Base Stations (R-RBS), whose HPR can be reconfigured in order to be used with different RATs, frequencies, channels, etc. In particular, the architecture foresees a Radio Controller managing the different access networks of each Radio Access Technology (e.g. GSM system and UMTS system) and one or more reconfigurable base station BS1, …, BSk. Each base station (BS1, …, BSk) is a multi-RAT base station (e.g. GSM and UMTS), able to manage different systems at the same time and to be reconfigured accordingly where the HPR are shared among the supported RATs. In addition, each reconfigurable base station
BS1, …, BSk can be reconfigured in terms of percentage of hardware processing resources devoted to each supported RAT and in terms of active radio resources (e.g. frequency carriers) for each supported RAT.

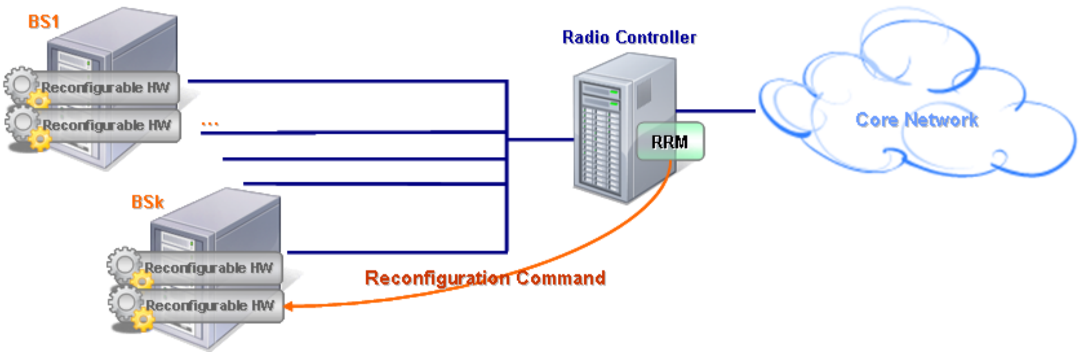

Figure 4: Reference architecture for Reconfigurable Base Stations Management

The Radio Controller includes the RRM (Radio Resource Management) entity which aim is to manage the request and the assignment of a radio channel to the mobile terminals that are in the cells managed by the base station BS1, …, BSk. In the reference architecture depicted above, the RRM has a new functionality called Hardware Reconfiguration Entity that is running the reconfiguration algorithm. This functionality is devoted to:

- monitor periodically the current activity status of the cells (for each supported RAT) in terms of measurement of the number of the requests and rejects (if any) from the different systems;
- execute the reconfiguration algorithm that decides which base station(s) are to be reconfigured;
- third, control the reconfiguration by sending appropriate reconfiguration commands (according to the algorithm output) to the base stations in order to reconfigure them.

It is worth to be noted that Hardware Reconfiguration Entity could be also placed inside a Core Network or O&M node or even inside each e-NodeB (e.g. in case of flat-architecture), supposing that it can opportunely interact with RRM and reconfigurable base stations entities).

Focusing on the reconfiguration algorithm, it determines which base station(s) has(have) to be reconfigured, with the aim to adapt the percentages of processing resources devoted to each supported RAT and to dynamically shape the active radio resources to the behaviour of the traffic. Thus, the Radio Controller commands the processing resource reconfiguration to the base station(s) through the interface between each base station BSk and the radio controller (e.g. using BTS Management - BTSM - protocol belonging to Abis interface of GSM system or NodeB Application Part - NBAP - protocol belonging to Iub interface of UMTS system). New protocol messages bearing the information to the base station for the appropriate reconfiguration action (e.g. processing resources and radio resources - such as frequency carriers - to activate/deactivate for each supported RAT) have to be introduced. Such process is applied to each base station involved in the reconfiguration process.

Further details of the algorithm and some results obtained for a 2G/3G scenario, are provided in [i.8].

5.4.4 Spectrum Sensing

Spectrum sensing is the act of measuring information indicative of spectrum occupancy (information may include frequency ranges, signal power levels, bandwidth, etc.). Spectrum sensing may provide additional information on how the sensed spectrum is used.

The main focus is on identifying unused areas in the intended frequency range that can be used by CRSs. Monitoring of spectrum usage and detection of systems present in the spectrum that are to be protected from harmful interference is a non-trivial technical problem, due to the well-known issues on "hidden nodes" and receive-only devices.

There are ways to mitigate those issues on detection of all spectrum users. Collaborative spectrum sensing techniques, where multiple nodes of the network share and combine their sensing results, have been subject to extensive research.

Sensing is a technology that is still under development. Sensing becomes more challenging when a wider range of frequencies and/or a wider range of technologies need to be taken into account. Therefore it might be useful to start with the introduction of CRSs in a limited frequency range in which the range of technologies used by the other existing users in the band is limited, e.g. within the UHF broadcasting bands.

Sensing is a key feature to protect the primary users but may not be sufficient in all cases.

5.4.5 Cognitive Pilot Channel

The concept of the Cognitive Pilot Channel (CPC) aims to support and facilitate end-to-end connectivity in a heterogeneous radio access environment. For instance, what is reported above becomes more relevant 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 spectrum awareness arises as a basic challenge in a generic scenario, where a number of transceivers even with flexible time-varying assignment of operating frequency and/or RAT are deployed. Spectrum awareness from the mobile's perspective refers to the mechanisms allowing the terminal to obtain knowledge of the communication means available at a given time and place, both at switch-on stage as well as during on-going operation.

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 by TC-RRS [i.4]. CPC can be advantageous in different scenarios.

A mobile terminal may use the CPC during one or both of the following phases:

- **"start-up"** phase: turning on, the terminal detects (e.g. on one or more well-known frequencies) the CPC and optionally could determine its geographical information by making use of some positioning system. The CPC detection will depend on the specific CPC implementation in terms of the physical resources being used. After detecting and synchronizing with the CPC, the terminal retrieves the CPC information corresponding to the area where it is located, which completes the procedure. Information retrieved by the mobile terminal is sufficient to initiate a communication session optimised to time, situation and location. In this phase, the CPC delivers relevant information with regard to operators, frequency bands, and RATs in the terminal location. During the start-up phase beginning at "switch on" of the mobile terminal, the mobile terminal is searching for a candidate network to camp on.

- **"ongoing"** phase: as soon as the terminal is registered to (or "camped on") a network, it leaves the "start-up" phase and is in the "on-going" phase situation. When the terminal is camped on to a network, a periodic check of the information forwarded by the CPC may be useful to rapidly detect changes in the environment due to either variations of the mobile position or network reconfigurations. In this phase, the same information of the "start-up" phase could be delivered by the CPC with additional data, such as services, load situation, etc. The ongoing phase ends when the mobile is no longer registered ("camped on") on any network.

Two CPC deployment options can be considered. The first one, out-band CPC, considers that a channel outside the bands assigned to component Radio Access Technologies provides CPC service. The second one, in-band CPC, uses a transmission mechanism (e.g. logical channel) within the technologies of the heterogeneous radio environment to provide CPC services.

Further technical details on the CPC concept and deployment are reported in [i.4].

5.4.6 Cognitive Control Radio and Networking

The Cognitive Control Radio (CCR) is an out-band peer-to-peer communication radio between heterogeneous radio network nodes for the exchange of cognition related information. It operates on a known frequency. It is meant for a cognitive frequency band, which is shared among multiple CRSs. The cognitive band may also be used by primary users.

By using the their Cognitive Control Radios the radio nodes belonging to different radio networks become connected to a multi-hop CCR network, as illustrated in figure 5.

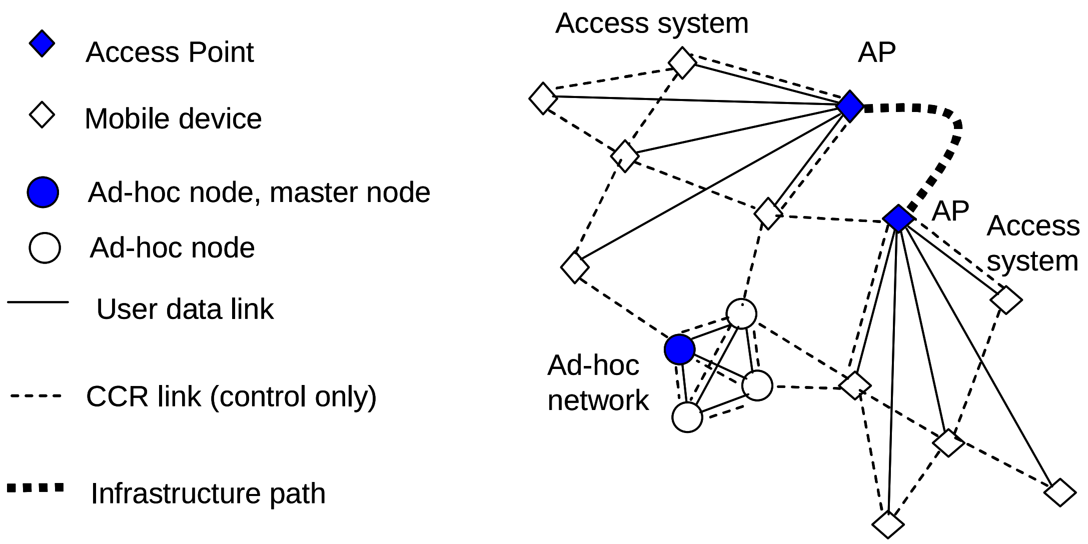

Figure 5: Cognitive Control Radio Network

The information transmitted in CCR network could include:

- Messages to assist a newly deployed node to find the frequency of its network.
- In case a network has a low node density, the co-located networks share their spectrum sensing results and their transmit/receive parameters over the CCR. In this way each network will get improved spectral context information.
- Negotiation messages about the spectrum use. The aim is to avoid conflicting spectrum use decisions through negotiation and improve fairness.

CCR Networking has been studied within the EU FP7 Project E3 [i.7].

5.4.7 Geolocation

Besides the information about the local radio spectrum environment another key contextual information assisting CR systems in their operations is geolocation awareness. It includes the ability of a device to determine its location as well as the locations of other transmitters or receivers.

5.4.8 Primary Protection Database

Primary protection database is the database that contains information on primary user radio systems operation in a particular frequency bands or channels, where secondary access is allowed by regulation in particular locations. The CRS is allowed to start operation only if the white space primary protection database indicates that there is no primary system operation in some frequency bands in locations where the CRS is deployed. The CRS is only allowed to use frequencies indicated by the primary protection database.

The database information about the primary systems starting operation in their frequency bands has may have some delay. This delay is equal to the delay between the time when a primary system starts transmission and the time when such information is reflected in the white space primary protection database and distributed to the CRS. During such delay, the white space database cannot be used to protect the primary system starting transmission from the harmful interference caused by the CRS operation. Correspondingly, the CRS performs spectrum sensing in its operational frequency bands in order to detect the primary system starting operation. If the primary system is detected, the CRS stops its operation.

Although there are many technical, operational, administrative and responsibility aspects in realization of primary protection databases for CRS, the protocols to query the database and contents of data within the database are among the key items to be considered for standardization.

5.4.9 Distributed Decision Making

The distributed decision making refers to the architecture of the management system inside the CRS responsible for making decisions on which parameters and protocols need to be adjusted, when, and how. Also, such management system will control the process of obtaining knowledge.

Depending on the deployment scenario, the CRS can include a lot of radio nodes distributed on a large territory. It is very difficult to manage such large CRS by one centralized management entity. More efficient and scalable approach is to develop distributed architecture of the CRS management system, where management functions are distributed between network side and terminal side, as well as, inside network.

For example, to perform network-terminal distributed decision making, the policy based management approach can be used. If terminal reconfiguration is considered, reconfiguration policies can be generated inside network and sent to terminals. Then, terminals can make final reconfiguration decisions within framework defined by these reconfiguration policies.

5.4.10 Other technical enablers

Management of cognitive information in CRSs could be supported by various databases.

6 CRS Standardization in other bodies

This clause summarizes the status and scope of CRS related standardization activities in other standardization bodies. More detailed information about these activities is available in annex A.

6.1 IEEE Standard P1900.4

Currently, IEEE 1900.4 standard [i.5] has been published. It describes management system that enables optimized radio resource usage in heterogeneous wireless access networks.

6.2 IEEE 802 activities on TV White Spaces

Working Groups (WG) of IEEE 802 LAN/MAN Standards Committee are defining both CRSs and components of CRS targeted to the TV White Space frequency band as identified by the US FCC.

6.3 ITU-R studies on Cognitive radio systems

The ITU-R Recommendation WP 1B is currently developing the working document towards draft CPM text on WRC-12 agenda item 1.19

The ITU-R Recommendation WP 5A is currently developing the working document towards a preliminary draft new report on "Cognitive radio systems in the land mobile service".

7 Conclusions and Recommendations

*This feasibility study has explored objectives and potential directions in spectrum use scenarios for future Cognitive Radio Systems. Some key technology components have been described as building blocks to enable development of a*n overall and harmonized technical concept for future Cognitive Radio Systems.

The feasibility study resulted into identification of two different but complementary approaches into CR system design:

- Network-centric approach, which addresses cognitive extensions to the network management system and utilizes Cognitive Pilot Channel (CPC) to convey cognitive control information between the network and user terminal devices.
- Distributed approach, where autonomous mobile devices establish mesh networks among themselves in ad-hoc manner and use Cognitive Control Radio (CCR) to enable distribution of cognitive information.

Assuming that both of these networking environments will develop towards utilizing CRS technologies also the interworking and coexistence solutions will need to be addressed in further research and standardization.

The following list of potential topics for ETSI standardization was already compiled in the TC-RRS Summary report [i.1]:

1) Access to regulatory information, e.g. a database protecting primary users.
2) Network architecture and protocols for a Composite Wireless Network (CWN).
3) Network Architecture and Protocols for Cognitive Control Radio (CCR) and Network.
4) Interface between OSM functions in different CWNs.
5) JRRM protocol between CWN and its terminals.
6) CPC radio and protocols.
7) Architecture and interfaces for SDR mobile device.
8) Architecture and interfaces for Reconfigurable RBS.

The topics listed above will need to be addressed with special attention to their security aspects.

Besides these specific technical topics the broader area of Cognitive Radio Systems for White Spaces will need to be addressed in the further studies and standardization.

Annex A: CRS Standardization in other bodies

A.1 CRS concept in IEEE 1900.4 system

A.1.1 Introduction

Currently, IEEE 1900.4 standard [i.5] has been published. It describes management system that enables optimized radio resource usage in heterogeneous wireless access networks.

Clause A.1 describes concept of CRS that has been used during development of IEEE standard 1900.4.

A.1.2 IEEE 1900.4 context

The IEEE 1900.4 standard considers the heterogeneous wireless environment shown in figure A.1. Such an environment may include multiple operators each operating one or several RANs. These RANs might utilize a range of different radio interfaces to communicate with terminals.

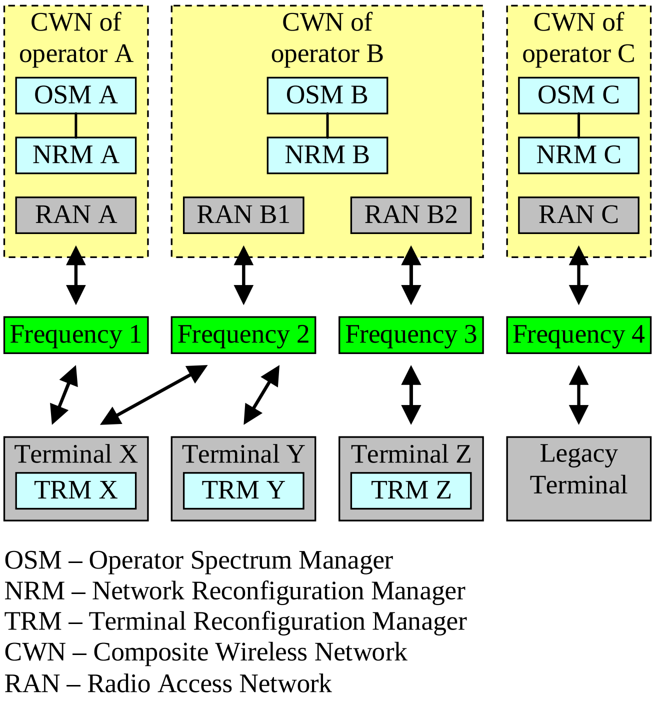

Figure A.1: Heterogeneous wireless environment considered in the IEEE 1900.4 standard

Advanced spectrum management capabilities are the topic of 1900.4. An example of such a capability is that where the assignment of spectrum to RANs can be dynamically changed, a "spectrum assignment" being characterized as a carrier frequency, a signal bandwidth, and the radio interface to be used in the given spectrum. Another example of advanced spectrum management is that where assignment of spectrum to RANs is fixed, but where some RANs are allowed to concurrently operate in more than one spectrum assignment.

RANs considered in the standard might be legacy or reconfigurable. Reconfiguration of RANs might be required, for example, to adjust to a new spectrum assignment. RANs may also perform dynamic reconfiguration while operating as a secondary system. Terminals considered in 1900.4 may be legacy or reconfigurable. Reconfigurable terminals may either possess or not possess multi-homing functionality. Multi-homing is defined as the capability of a reconfigurable terminal to have more than one simultaneous active connection with RANs.

The underlying objective in 1900.4 is to define a management system which decides upon a set of actions required to optimize radio resource usage and improve QoS in this heterogeneous wireless environment. In particular, the IEEE 1900.4 standard defines the entities and interfaces of this management system. The two key management entities are defined, as shown in figure A.1: the Network Reconfiguration Manager (NRM), and the Terminal Reconfiguration Manager (TRM). NRM is the decision making entity on the network side, responsible for the reconfiguration of RANs, while the TRM is the decision making entity on the terminal side, responsible for reconfiguration of the terminal hosting it. One further management entity is shown in figure A.1, the Operator Spectrum Manager (OSM). The OSM allows the operator to have overarching control of spectrum assignments to RANs.

The composition of the heterogeneous wireless environment with 1900.4 management entities creates a "Composite Wireless Network (CWN)". This composition possesses advanced capabilities with the flexibility to optimize radio resource usage therefore improving QoS.

A.1.3 IEEE 1900.4 use cases

The IEEE standard 1900.4 defines three use cases:

- Dynamic spectrum assignment;
- Dynamic spectrum sharing; and
- Distributed radio resource usage optimization.

These use cases are illustrated in figure A.2.

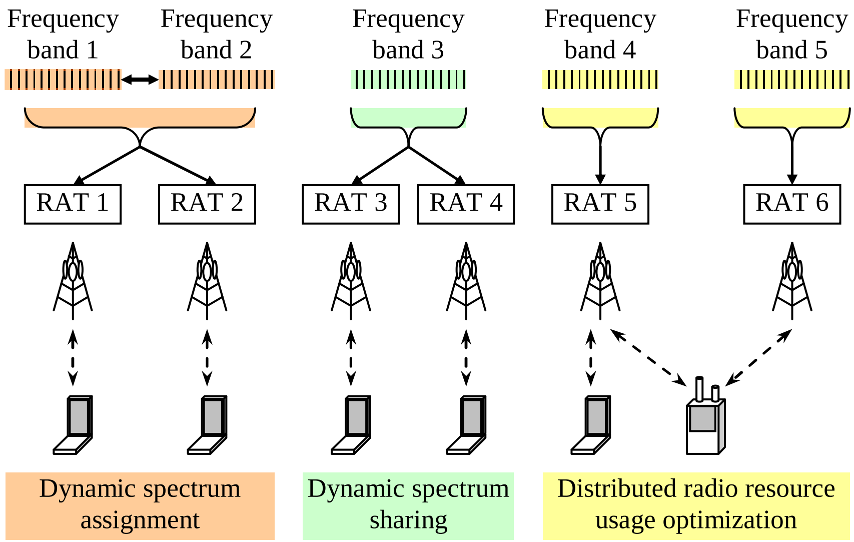

Figure A.2: IEEE 1900.4 use cases

In the **dynamic spectrum assignment** use case, frequency bands are dynamically assigned to RANs in order to optimize radio resource usage and improve QoS. The OSM generates spectrum assignment policies expressing the regulatory framework as well as the operator's objectives for spectrum usage optimization. The OSM then provides these spectrum assignment policies to its corresponding NRM, whereby each NRM analyzes these received policies and available context information, and dynamically makes assignment decisions using these inputs. After the new spectrum assignment decisions have been made, each NRM requests corresponding reconfigurations of its RANs. Following RAN reconfigurations, terminals may also need to reconfigure.

In the **dynamic spectrum sharing** use case, frequency bands assigned to RANs are fixed; however, a particular frequency band can be shared by several RANs in order to optimize radio resource usage and improve QoS. NRMs analyze available context information and dynamically make decisions about whether to access new frequency band. Following these decisions, NRMs request corresponding reconfigurations of their RANs. Also, NRMs dynamically generate radio resource selection policies, and send them to their TRMs. TRMs then analyze these radio resource selection policies and available context information, and dynamically make decisions as to whether their terminals should access new frequency bands; these decisions are made within the framework of the radio resource selection policies as conveyed by the NRM. Following these decisions, TRMs request corresponding reconfigurations of their terminals, where necessary. It should be noted that the dynamic spectrum sharing use case includes the primary/secondary spectrum usage scenario as a special case.

In the **distributed radio resource usage optimization** use case, frequency bands assigned to RANs are fixed. Furthermore, the reconfiguration of RANs is not considered, instead, the topic is constrained to reconfigurable terminals with or without multi-homing capability. In this use case, NRMs analyze available context information, dynamically generate radio resource selection policies, and send them to their TRMs. TRMs analyze these radio resource selection policies and available context information, and dynamically make decisions on reconfigurations of their terminals in order to improve radio resource usage and QoS. Again, these decisions are made within the framework of the radio resource selection policies conveyed by NRMs. Following these decisions, TRMs request corresponding reconfigurations of their terminals, where necessary.

A.1.4 CRS concept in IEEE 1900.4

The following CRS concept has been used during development of the IEEE standard 1900.4.

The IEEE 1900.4 standard considers the heterogeneous wireless environment characterized by the existence of the following components:

- Multiple operators operating different RANs.
- Multiple RANs using different radio interfaces to provide different wireless services.
- Reconfigurable and non-reconfigurable RANs.
- Reconfigurable and non-reconfigurable terminals.
- Different frequencies assigned to these RANs.

This heterogeneous wireless environment can be considered as a heterogeneous wireless network, given that different RANs can be connected via packet based core network(s) and/or Internet.

Such heterogeneous wireless environment potentially has a lot of possibilities to optimize spectrum usage and improve QoS. Examples of such optimization and improvement described in the IEEE 1900.4 standard are as follows:

- Dynamic spectrum assignment, where frequencies can be dynamically assigned to RANs.
- Dynamic spectrum sharing, where one frequency can be shared by several RANs.
- Distributed radio resource usage optimization, where reconfigurable terminals can dynamically select RANs to connect to.

To enable optimization of spectrum usage and improvement in QoS, intelligent management system is deployed on top of such heterogeneous wireless environment. Specification of such intelligent management system is the scope of the IEEE 1900.4 standard.

Taking into account generally large size of heterogeneous wireless environment currently existing, IEEE 1900.4 management system is distributed, where distribution is done between network side and terminal side, as well as, within the network side.

Three types of management entities are defined in the architecture of the IEEE 1900.4 management system:

- Measurements collectors responsible for collecting context information.
- Decision making entities responsible for making reconfiguration decisions in a distributed manner.

- Reconfiguration controllers responsible for controlling reconfiguration execution.

These types of management entities correspond to three commonly accepted cognitive functions. From this perspective, the IEEE 1900.4 management system enables cognitive capabilities in the heterogeneous wireless environment.

Correspondingly, in the IEEE 1900.4 standard it is assumed that CRS is a composition of the following three components:

- Heterogeneous wireless network, where some parts of such network are reconfigurable.
- Terminals, where some terminals are reconfigurable.
- Intelligent management system deployed within the other two components.

A.2 CRS Standardization in IEEE 802 LAN/MAN Standards Committee

Working Groups (WG) of IEEE 802 LAN/MAN Standards Committee are defining both CRSs and components of CRS.

Activities to define CRSs are currently performed in WGs 802.22 and 802.11:

- IEEE 802.22 [i.10] WG:
  - IEEE draft standard P802.22 for Cognitive Wireless RAN.
- IEEE 802.11 [i.11] WG:
  - IEEE draft standard P802.11af for TV White Spaces Operation.

Activities to define components of CRS are currently performed in WGs 802.21, 802.22, and 802.19:

- IEEE 802.21 [i.12] WG:
  - IEEE standard 802.21 for Media Independent Handover.
- IEEE 802.22 [i.10] WG:
  - IEEE draft standard P802.22.1 for Enhancing Harmful Interference Protection for Low Power Licensed Devices Operating in TV Broadcast Bands.
- IEEE 802.19 [i.14] WG:
  - IEEE draft standard P802.19.1 for TV White Space Coexistence Mechanisms.

The rest of this clause provides brief overview of each of these activities.

A.2.1 Activities to define Cognitive Radio Systems

A.2.1.1 IEEE draft standard P802.22

IEEE P802.22 is entitled "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" [i.9], [i.10].

The scope of the draft standard is as follows. "This standard specifies the air interface, including the cognitive medium access control layer (MAC) and physical layer (PHY), of point-to-multipoint wireless regional area networks, comprised of a professionally installed fixed base station with fixed and portable user terminals operating in the unlicensed VHF/UHF TV broadcast bands between 54 MHz and 862 MHz (TV Whitespace)".

The purpose of the draft standard is as follows. "This standard is intended to enable deployment of interoperable 802 multivendor wireless regional area network products, to facilitate competition in broadband access by providing alternatives to wireline broadband access and extending the deployability of such systems into diverse geographic areas, including sparsely populated rural areas, while preventing harmful interference to incumbent licensed services in the TV broadcast bands".

A.2.1.2 IEEE draft standard P802.11af

IEEE draft standard P802.11af is entitled "IEEE Standard for Information Technology - Telecommunications and Information Exchange Between Systems - Local and Metropolitan Area Networks - Specific Requirements - Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications - Amendment: TV White Spaces Operation" [i.11].

The scope of the draft standard is as follows. "An amendment that 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".

The purpose of the draft standard is as follows. "The purpose of this amendment is to allow 802.11 wireless networks to be used in the TV white space".

A.2.2 Activities to define components of Cognitive Radio System

A.2.2.1 IEEE standard 802.21

IEEE 802.21 is entitled "IEEE Standard for Local and metropolitan area networks - Part 21: Media Independent Handover Services" [i.12].

The scope of the standard is as follows. "This standard defines extensible IEEE 802 media access independent mechanisms that enable the optimization of handover between heterogeneous IEEE 802 networks and facilitates handover between IEEE 802 networks and cellular networks".

The purpose of the standard is as follows. "The purpose is to improve the user experience of mobile devices by facilitating handover between IEEE 802 networks whether or not they are of different media types, including both wired and wireless, where handover is not otherwise defined; and to make it possible for mobile devices to perform seamless handover where the network environment supports it. These mechanisms are also usable for handovers between IEEE 802 networks and non IEEE 802 networks".

A.2.2.2 IEEE draft standard P802.22.1

IEEE P802.22.1 is entitled "Standard to enhance harmful interference protection for low power licensed devices operating in TV Broadcast Bands" [i.13].

The scope of the draft standard is as follows. "This standard specifies methods to provide enhanced protection to protected devices such as those used in the production and transmission of broadcast programs (e.g. devices licensed as secondary under Title 47 of the Code of Federal Regulations (CFR) in the USA and equivalent devices in other regulatory domains) from harmful interference caused by licensed-exempt devices (such as, e.g. IEEE 802.22 [i.10]) that also are intended to operate in the TV Broadcast Bands".

The purpose of the draft standard is as follows. "This standard provides a standard and efficient method for license-exempt devices to provide enhanced protection to low powered licensed devices that are entitled to protection from harmful interference, and that share the same spectrum. This standard may be applicable in global regulatory environments".

A.2.2.3 IEEE draft standard P802.19.1

IEEE draft standard P802.19.1 is entitled "IEEE Standard for Information Technology - Telecommunications and Information Exchange Between Systems - Local and Metropolitan Area Networks - Specific Requirements - Part 19: TV White Space Coexistence Methods" [i.14].

The scope of the draft standard is as follows. "The standard specifies radio technology independent methods for coexistence among dissimilar or independently operated TV Band Device (TVBD) networks and dissimilar TV Band Devices".

The purpose of the draft standard is as follows. "The purpose of the standard is to enable the family of IEEE 802 Wireless Standards to effectively use TV White Space by providing standard coexistence methods among dissimilar or independently operated TVBD networks and dissimilar TVBDs. This standard addresses coexistence for IEEE 802 networks and devices and will also be useful for non IEEE 802 networks and TVBDs".

A.3 ITU-R activities related to CRS

The ITU-R Recommendation WP 1B is currently developing the working document towards draft CPM text on WRC-12 agenda item 1.19. The agenda item 1.19 is "to consider regulatory measures and their relevance, in order to enable the introduction of software-defined radio and cognitive radio systems, based on the results of ITU-R studies, in accordance with Resolution 956 (WRC 07)" [i.15].

To prepare the working document, WP 1B has developed definitions of the SDR and CRS. Also, WP 1B has summarized the technical and operational studies and relevant ITU-R Recommendations related to the SDR and CRS. WP 1B has considered the SDR and CRS usage scenarios in different radio services. Currently, WP 1B is considering the international radio regulation implications of the SDR and CRS.

The ITU-R Recommendation WP 5A is currently developing the working document towards a preliminary draft new report on "Cognitive radio systems in the land mobile service" [i.16]. This report will address the definition, description and application of cognitive radio systems in the land mobile service.

The following topics related to CRS are currently considered in the working document:

- Technical characteristics and capabilities
- Potential benefits
- Deployment scenarios
- Potential applications
- Operational techniques
- Coexistence
- Impact on spectrum management:
    - Operational implications
    - Technical implications

Annex B: Bibliography

ETSI TR 102 681: "Reconfigurable Radio Systems (RRS); Radio Base Station (RBS) Software Defined Radio (SDR) status, implementations and costs aspects, including future possibilities".

ETSI TR 102 745: "Reconfigurable Radio Systems (RRS); User Requirements for Public Safety".

History

Document history		
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