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Technical Report

**Reconfigurable Radio Systems (RRS);
Summary of feasibility studies and
potential standardization topics**

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Foreword

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

Introduction

The present document summarizes the feasibility studies carried out by ETSI TC-RRS since the establishment of the Technical Body in January 2008. The area of studies has been Software Defined and Cognitive Radio Systems - collectively called Reconfigurable Radio Systems.

In addition to the (interim) summary of the still ongoing studies the present document also summarizes the so far identified topics, which are regarded by TC-RRS as candidates for creating ETSI Technical Specifications.

This summary in the present document provide basis for decision making at ETSI Board level on standardization of some or all topics of Reconfigurable Radio Systems.

1 Scope

The present document provides summary of the feasibility studies and work carried out by TC-RRS and its Working Groups since January 2008. The Working Groups are responsible for following study areas:

- WG1: RRS System Aspects.
- WG2: Reconfigurable Radio Equipment Architecture.
- WG3: Functional Architecture and Cognitive Pilot Channel (in Cognitive Radio Network Management).
- WG4: RRS Public Safety.

Furthermore, aspects not covered by the RRS Working Groups have also been added, see clause 6.

As a whole these studies have covered radio system technologies more generally known as Software Defined Radio and Cognitive Radio. The present document contains proposals for standardization in this area.

2 References

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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 102 680: "Reconfigurable Radio Systems (RRS); SDR Reference Architecture for Mobile Device".

[i.2] ETSI TR 102 681: "Reconfigurable Radio Systems (RRS)); Radio Base Station (RBS) Software Defined Radio (SDR) status, implementations and costs aspects, including future possibilities".

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

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

[i.5] ETSI TR 102 745: "Reconfigurable Radio Systems (RRS); User requirements for Public Safety".

3 Definitions and abbreviations

3.1 Definitions

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

Cognitive Radio System (CRS): radio system, which has the following capabilities:

- to obtain the knowledge of radio operational environment and established policies and to monitor usage patterns and users' needs;
- to dynamically and autonomously adjust its operational parameters and protocols according to this knowledge in order to achieve predefined objectives, e.g. more efficient utilization of spectrum; and
- to learn from the results of its actions in order to further improve its performance.

NOTE 1: Radio operational environment encompasses radio and geographical environments, and internal states of the Cognitive Radio System.

NOTE 2: To obtain knowledge encompasses, for instance, by sensing the spectrum, by using knowledge data base, by user collaboration, or by broadcasting and receiving of control information.

NOTE 3: Cognitive Radio System comprises a set of entities able to communicate with each other (e.g. network and terminal entities and management entities).

NOTE 4: This definition follows the preliminarily proposal of ITU-R WP5A and may need to be changed accordingly.

digital dividend: "leftover" frequencies resulting from the change of TV broadcasting from analogue to digital transmission schemes

Reconfigurable Radio Systems (RRS): generic term for radio systems encompassing Software Defined and/or Cognitive Radio Systems

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.

software defined radio: radio in which the RF operating parameters including, but not limited to, frequency range, modulation type, or output power can be set or altered by software, and/or the technique by which this is achieved

NOTE 1: Excludes 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 2: SDR is an implementation technique applicable to many radio technologies and standards.

NOTE 3: SDR techniques are applicable to both transmitters and receivers.

white space: frequency band allocated to a broadcasting service but not used locally (e.g. in time and/or space)

3.2 Abbreviations

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

CCM	Configuration Control Module
CCN	Cognitive Control Network
CMN	Cognitive Mesh Network
CN	Cognitive Network
C-NMS	Cognitive Network Management System
CPC	Cognitive Pilot Channel
CR	Cognitive Radio
CRS	Cognitive Radio System
CWN	Composite Wireless Network
DSA	Dynamic Spectrum Allocation
DSM	Dynamic Spectrum Management
DSONPM	Dynamic Self-Organizing Network Planning and Management
FA	Functional Architecture
FCC	Federal Commission for Communications
GPRS	General Packet Radio Service
GSM	Global Service for Mobile communication
JRRM	Joint Radio Resource Management
LTE	Long Term Evolution
MAC	Medium Access
MD	Mobile Device
MUE	Multiradio User Equipment
OEM	Original Equipment Manufacturer
OSM	Operator Spectrum Management
PMR	Professional Mobile Radio
RAT	Radio Access Technology
RBS	Radio Base Station
RF	Radio Frequency
R-RBS	Reconfigurable Radio Base Station
RRM	Radio Resource Management
RRS	Reconfigurable Radio System
SDR	Software Defined Radio
SW	Soft Ware
TCAM	Telecommunications Conformity Assessment and Market Surveillance Committee
UHF	Ultra High Frequency
UMTS	Universal Mobil Telecommunications System
WWRF	Wireless World Research Forum

4 Reconfigurable Radio Systems

There are several factors driving the future evolution of radio technologies towards more flexible and reconfigurable 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 share 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 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.

4.1 Network Architectures for Reconfigurable Radio Systems

In the context of TC RRS studies Reconfigurable Radio Systems are regarded as networks having high-level structures with the following system components as illustrated in figure 1.

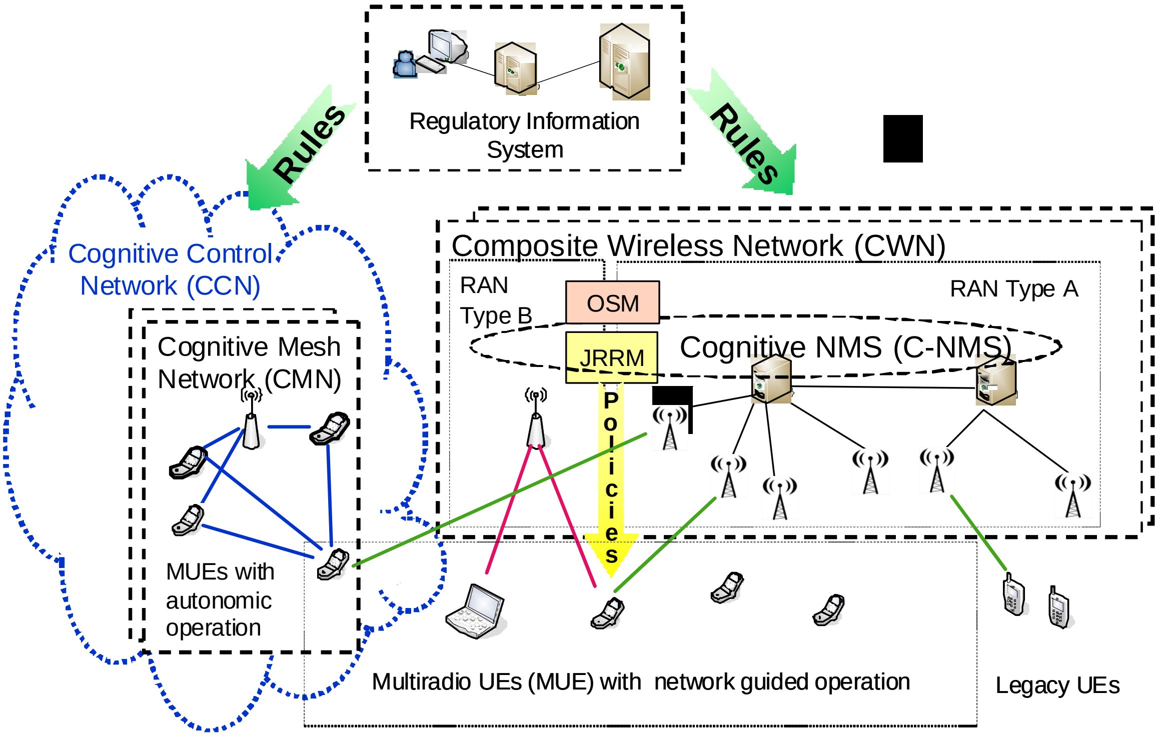

Figure 1: Centralized and decentralized CR system concepts

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 priminary 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.

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

Joint Radio Resource Management (JRRM) 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 adhoc 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.

4.2 Communication Planes in RRS Network Elements

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

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

The feasibility studies of the TC-RRS 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 Summary of TC-RRS Studies

The different Working Groups of TC-RRS have studied various aspects of RRS network architectures:

- WG1: RRS System Aspects.
- WG2: Reconfigurable Radio Equipment Architectures (covering both MUE and R-RBS) [i.1] and [i.2].
- WG3: Functional Architecture and Cognitive Pilot Channel (in Cognitive Network Management) [i.3] and [i.4].
- WG4: RRS Public Safety [i.5].

The following clauses describe the key findings and conclusions from these different studies.

5.1 System Aspect Studies (WG1)

The ongoing studies in the System Aspects Working Group (WG1) have focused into formulation of an overall technical framework onto which the various topics being studied in other working groups can be mapped. The high-level structures for both centralized and decentralized CR system concepts as described in clause 4 represents the current status of this study. It also serves the purpose of identifying the candidate subjects for standardization as outlined in clause 7.

The current studies carried out by WG1 are also covering investigation of the possible regulatory impacts of the RRS technologies.

5.2 Reconfigurable Radio Equipment Studies (WG2)

WG2 finalized two study reports targeting the identification of potential SDR standardization axes for both, the Mobile Devices (MD) and Reconfigurable Base Stations (RBS). The titles of these reports and the corresponding recommendations given as a result of the studies are indicated below:

- "Reconfigurable Radio Systems (RRS); SDR Reference Architecture for Mobile Device (TR 102 680 [i.1])". The results of the corresponding study include the following items:
    - Different architectural interfaces and radio programming model are derived from the SDR value network. They represent key interfaces between the different stakeholders in the value network as follows:
        - Multiradio Access Interface represents the technical interface between radio computer platform providers and mobile device manufacturers.
        - Unified Radio Application Interface together with Radio Programming Model and Interface represent the technical interfaces between radio application software vendors and radio computer platform providers.
        - Reconfigurable RF Interface represents the technical interface between RF circuit vendors and radio computer platform providers.
    - As a study result, it is recommended that ETSI TC-RRS proceeds to create ETSI Technical Specifications for:
        - SDR Reference Architecture Specification for Mobile Device.
        - Specification of Multiradio Access Interface for Mobile Device.
        - Specification of Unified Radio Application Interface for Mobile Device.
        - Radio Programming Model and Interface Specification for Mobile Device.
        - Specification of Reconfigurable RF Interface for Mobile Device.
- "Reconfigurable Radio Systems (RRS); Radio Base Station (RBS) Software Defined Radio (SDR) status, implementations and costs aspects, including future possibilities (see TR 102 681 [i.2])". The results of the corresponding study include the following items:
    - The need for reconfigurable radio base stations and their requirements have been collected and analyzed. Telecom operator requirements stated a need for reconfigurable radio base station, in order to achieve:
        - Fast network planning and update according to capacity and coverage needs.
        - Fast and cost efficient network deployment and commissioning.
        - Flexible network operation especially with respect to technology migration, spectrum reuse.
        - Maintenance optimization.
    - Also from telecom OEMs a need for reconfigurable RBS has been identified, mainly to:
        - Efficiently follow different customer requirements.
        - Reduce number of product variants and allow efficient product management.

- At a first stage, from the collected requirements a potential standardization item could be derived on the topic of open and standardized interface(s) in order to manage fast and flexible network planning and operation, and related resource management. However, the study has been limited to SDR architectures, without taking additional possible requirements from e.g. Cognitive Radio (CR) into account. Therefore further activity is envisaged to support more specifically the related standard development. Requirements originating from extended functionalities, as e.g. CR, are likely to further impact the standardization of related aspects.

- The new SDR technology network devices should fully meet the requirements and technical specifications of the 3GPP standards, thus also guaranteeing the complete interoperability among them. In addition, standardized interfaces should ensure soft evolution and software upgrade of deployed SDR technology radio access networks to new standards.

- The working group developed a high level reconfigurable RBS reference architecture and described the basics of the ten most relevant interfaces for this architecture. Several of the described functionalities and interfaces could have potential for standardization, but none of those have yet been proposed for standardization by the ETSI members, which have participated the TC-RRS work.

- The concept of a dual mode mobile device / home RBS has been presented. It has been proposed to standardize a mobile device / home RBS architecture and inherent interfaces. However, possible requirements and details for such a device are not covered in this work item.

The study results of ETSI RRS WG2 relate to the *Network Architectures for Reconfigurable Radio Systems* as illustrated by figure 1 as follows:

- With the focus on SDR aspects of the *Network Architectures for Reconfigurable Radio Systems*, ETSI RRS results focus on SDR as *Enabling Technology* supporting the CR functionalities introduced by WG3 and by enabling the inherent operational requirements. In particular, these are:
  - MUE: Definition of a framework that enables the simultaneous operation of a multitude of standards, composite wireless networks and multiradio terminals. Furthermore, the proposed framework enables the efficient development and deployment of new standards, update of equipment that is already deployed in the field and continuous adaptation to evolving regulatory requirements.
  - CMN: Definition of a framework that enables the operation of a mesh network, including the continuous adaptation of operated standards following the requirements of peer equipment.
  - CWN: WG2 proposes standardization axes targeting:
    i) fast network planning and update according to capacity and coverage needs;
    ii) fast and cost efficient network deployment and commissioning;
    iii) flexible network operation especially with respect to technology migration, spectrum reuse;
    iv) maintenance optimization including standardized access to SDR parameters by RBS operators.

5.3 Cognitive Network Management Studies (WG3)

The work in WG3 is split into two work items: Functional Architecture (FA) and Cognitive Pilot Channel (CPC).

5.3.1 Functional Architecture (FA) for the Management and Control of Reconfigurable Radio Systems

The scope of TR 102 682 [i.3] is to study and propose a generic architecture for the management and control of reconfigurable radio systems, namely the Functional Architecture (FA). The FA is designed to improve the utilization of spectrum and radio resources.

Example scenarios which show the benefits of the modules described in the FA include:

- Spectrum on demand where operators can negotiate on e.g. to rent some part of the spectrum to another operator.

- Initial scan scenario in an environment with dynamic spectrum allocation where a terminal arrives in a new place (in geography) where the terminal has no knowledge of the environment, i.e. what radio accesses that are available, what services are available and frequencies that are used, etc. The terminal then has to find and start using the most suitable (or just a suitable) access.
- Terminal reconfiguration.
- Network reconfiguration.

The main modules included in the FA as shown in 2 are:

a) Dynamic Spectrum Management (DSM) which contains and provides policies on spectrum usage, including the legal framework and supports dynamic spectrum assignment.

b) Dynamic Self-Organizing Network Planning and Management (DSONPM) for the optimal configuration of the network.

c) Joint Radio Resource Management (JRRM) for multi-standard radio resource management, selects the best radio access for a user and providing Neighbourhood information to the terminals.

d) Configuration Control Module (CCM) to execute the reconfigurations either of a terminal or a base station.

Since the feasibility of standardization of FA for radio systems also depends on already standardized or ongoing activities on such architectural elements TR 102 682 [i.3] also provides a survey on FA related standardization in other standardization bodies like IEEE and 3GPP.

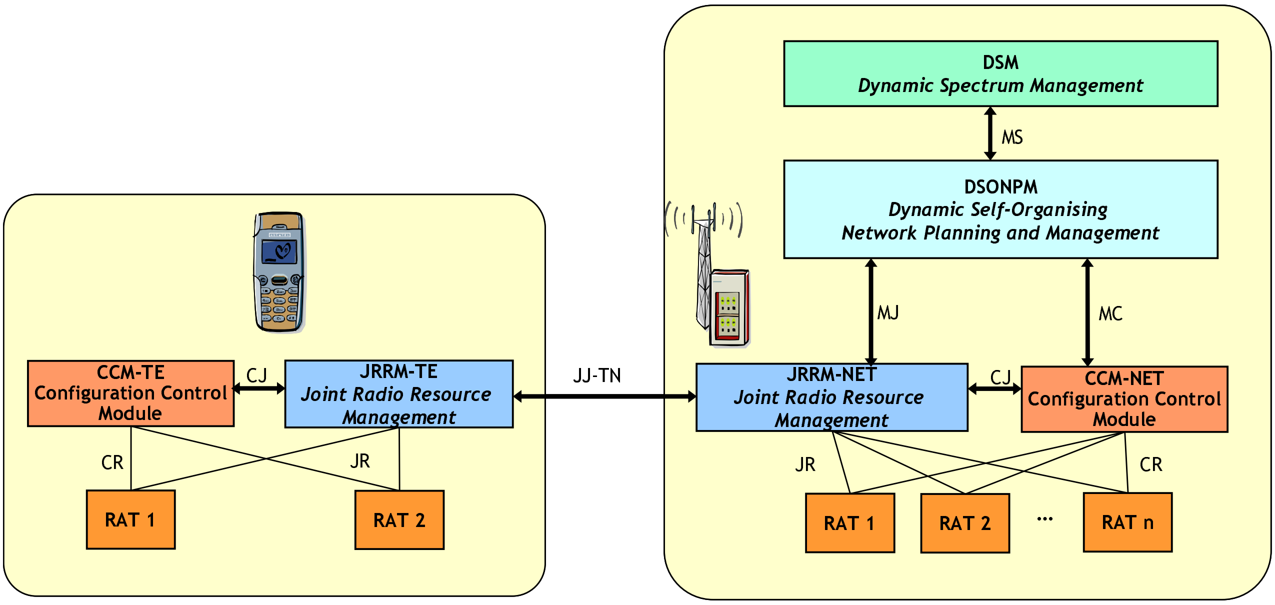

Figure 2: High level view of Functional Architecture (single-operator viewpoint)

Concrete technical examples where standards would be beneficial are listed below, in conjunction with the proposed FA:

- A cognitive radio network will need standards to avoid interferences, enhance the speed and the efficiency of this type of operation providing terminal user's satisfaction. This work is expected to be continued in conjunction with WG1 "Cognitive Radio Systems Concept" of TC RRS to which the outcomes of the present document will be provided.
- In addition, having standards in the areas covered by the proposed FA would help network operators and network business owners from various countries to face the increasing subscriber's need to reach a worldwide network, in a globalization context.
- From an operator viewpoint, it is desirable to be able to diversify the range of its equipment vendors. In this respect, the standardization of the interfaces between functional blocks (JRRM, CCM, DSONPM, etc.) as defined in this FA will be very beneficial.

As a result from the feasibility study on the FA, it is recommended that ETSI TC RRS proceeds to create ETSI Technical Specifications for:

- Functional architecture of reconfigurable radio systems, meaning the proposed functional blocks that are necessary for the management and control of radio resources in reconfigurable radio systems.
- Specification of interfaces among the FA functional blocks, so as to facilitate the production of the functional blocks by various vendors, intercommunicating through standardizes interfaces. It has to be noted that standardization in ETSI should focus on those interfaces which are not subject of standardization in other bodies.
- Specification of the protocol messages to be exchanged among the FA functional blocks.

5.3.2 Cognitive Pilot Channel (CPC)

The current trend for radiocommunications systems indicates a composite radio environment, where multiple Radio Access Technologies (RATs) and corresponding frequencies links may be available at the same time. In this context, the cognitive capability of the nodes becomes increasingly a crucial point to enable optimization of the radio usage. In order to obtain knowledge of its radio environment, a cognitive radio device may sense parts of the spectrum, which is necessary for its intention. This task may result in a very time and power consuming operation, if the parts of the spectrum to be sensed are large. In this context, the Cognitive Pilot Channel (CPC) solution could lead to a more efficient approach by conveying elements of the necessary information to let the terminal obtain knowledge of e.g. the available frequency bands, RATs, services, network policies, etc., through a kind of common pilot channel.

Two CPC deployment options have been developed in the context of Cognitive Networks (CN) for Reconfigurable Radio Systems (RRS). The first one, out-band CPC, is a CPC conceived as a radio channel outside the component Radio Access Technologies (e.g. CPC either uses a new radio interface, or alternatively uses an adaptation of legacy technology with appropriate characteristics). The second one, in-band CPC, uses a transmission mechanism (e.g. logical channel) within the technologies of the heterogeneous radio environment.

Exemplary scenarios where the CPC is seen as useful are:

- The CPC can be used to support a terminal during the start-up phase, conveying the necessary information to let the terminal know the available RATs and corresponding used frequencies in a given geographical area (see figure 3) An example of the data structure of the information transported over the CPC is shown in figure 4. The figure shows mainly RAT_LIST info.
- In the context of a secondary system the CPC can be used to exchange sensing information between terminals and base stations in order to perform collaborative/cooperative sensing facilitating the searching of white spaces to start communication.
- The CPC can be used for a more efficient level of collaboration between a network and the terminals by supporting Radio Resource Management (RRM) optimization procedures and additionally for an optional dynamic spectrum access and flexible spectrum management.

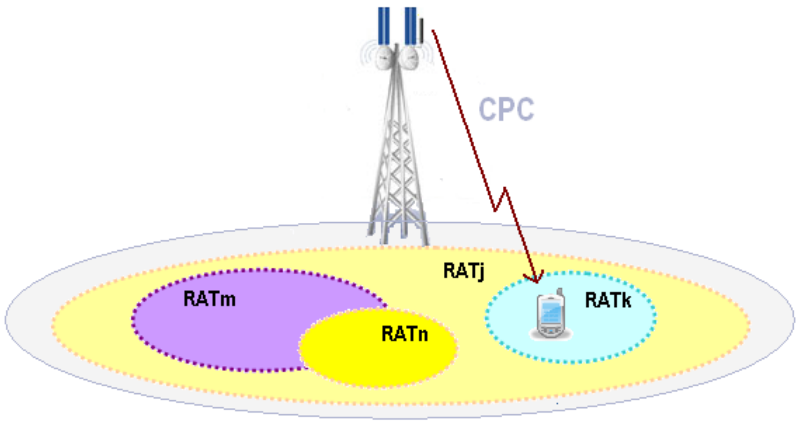

Figure 3: CPC providing information from the network to the terminals in a heterogeneous environment

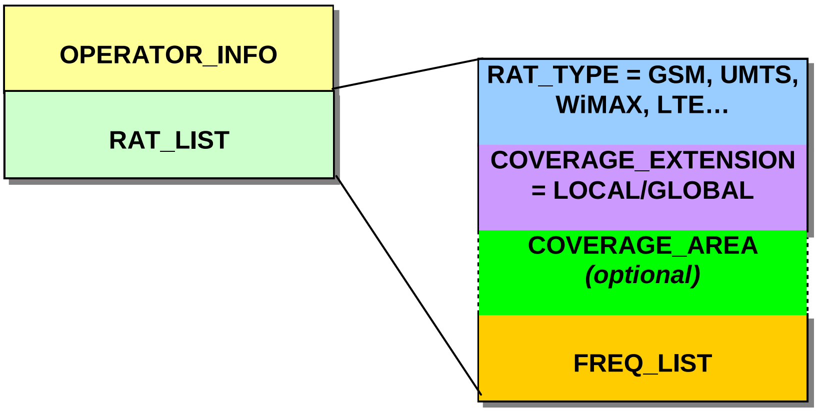

Figure 4: CPC information structure focusing mainly on RAT_LIST part

The standardization of CPC would be beneficial because:

- From an operator viewpoint standardization of the CPC could facilitate the managing of both the start-up and on-going phases, helping the mobile terminal to identify the spectrum availability, to select the proper network, to provide support to Joint Radio Resource Management (JRRM), and in summary to enable a more efficient use of the radio resources.
- Providing support to reconfigurability by allowing the terminal to identify the most convenient RAT to operate with and allowing the terminal to reconfigure its capabilities if necessary, e.g. facilitating advanced radio resources management strategies.
- As a key enabler for Cognitive Networks, the CPC can facilitate the secondary spectrum usage, avoiding/minimizing interferences, trying to enhance the efficiency of this type of communications.

From the feasibility study it is apparent that further technical research activities on this field are still needed and are currently underway in different research projects. Nevertheless, proposed inputs for a possible standardization of the CPC are provided:

- Definition and specification of physical and data link layer (L1 and L2) technologies and protocols for the out-band CPC in both downlink only and bidirectional operation. This should include the definition of the message structure and delivery procedures for cases like using the CPC concept for speeding up the start-up procedure in the context of a full DSA environment, for using the CPC as a support for secondary spectrum usage and for using the CPC as a support to radio resource management optimization.
- Definition and specification of message structure and delivery procedures for the in-band CPC for example to support radio resource usage optimization in the context of heterogeneous wireless environments.

5.4 Public Safety Studies (WG4)

WG4 has investigated the application of RRS to the Public Safety domain in two work items: User Requirements and Systems Aspects. User Requirements are used as input for the definition of the System Aspects.

Operational requirements for communication systems in the Public Safety domain are usually different from the Commercial domain especially in terms of reliability, availability, responsiveness and security.

The first step of the WG4 activity has been to collect and examine findings from other projects and organizations in this area. European projects financed by the Framework Program are an important reference, especially the WINTSEC project, which focused on the application of RRS technology (described as SDR in the project) to remove the existing interoperability barriers among Public Safety organizations. The NARTUS/PSCE project has the objective to establish a European platform and roadmap for future public safety communication, in order to facilitate European integration in the area of Public Safety with particular focus on public safety communications and information systems.

ETSI committees like Project MESA and ETSI EMTEL have also been main sources of information both for user requirements and systems aspects. Even if both entities are not focused specifically to Reconfigurable Radio Technologies, they have provided an essential input to define the context and challenges of Public Safety communications.

WG4 identified the following factors, which can drive the application of RRS in the Public Safety domain:

- Public Safety domain is characterized by many different wireless heterogeneous networks like TETRA, TETRAPOL, Analogy Professional Mobile Radio (PMR) and satellite communications. In some cases, commercial systems like GSM/GPRS are used. In large national disasters, military entities (like the Army) operate together with Public Safety organizations. As a consequence, there is an issue of interoperability when an emergency crisis is to be resolved by different public safety organizations equipped with different communication systems. RRS can be a technology enabler to resolve the interoperability barriers at technical level by activating the needed waveforms on the RRS platform.

- New Public Safety applications (Mobile Id, Mobile surveillance) or the evolution of existing applications (criminal identification) require an increase of broadband communications and high data rate communications, but it is not easy to assign, at regulatory level, additional spectrum bands for these applications. In the current approach of fixed spectrum management, the radio spectrum is highly contented by various stakeholders in the commercial, public safety and defence domain. A flexible spectrum management could provide the additional communications resources, by reserving a large portion of the radio spectrum in case of a natural disaster or an emergency crisis. In normal operations, the radio spectrum would be used by commercial providers. A number of organizational and technical challenges have still to be resolved to accomplish this vision.

- The upgrade and replacement of the Public Safety communications infrastructure and terminals is a rather expensive and complicate process. Thanks to the higher level of flexibility and reconfigurability in comparison to conventional radio communication technologies, RRS could mitigate the upgrading process and allow Public Safety organizations to use equipment in line with the technological progress.

WG4 has also identified other benefits on the application of RRS to the Public Safety domain, which are described in the related WG4 Technical Reports.

Even with the drivers described above, there are a number of significant challenges to be resolved before RRS technology can be adopted in the Public Safety domain.

If a Dynamic Spectrum Management approach is proposed, its design and deployment should be achieved accordingly to the user requirements identified by WG4.

WG4 identified the design of the Cognitive Network Management System as one of the main areas to investigate in the standardization effort. WG4 is currently defining models of Cognitive Network Management System, which could be applied to the Public Safety domain. Simulations are used to validate the models against the user requirements.

As described above, one of the potential benefits of RRS is to remove the interoperability barriers among Public Safety wireless systems. Interoperability can be provided at different levels in the network:

- At the level of the network infrastructure as a gateway among two or more network interfaces.

- At the level of base stations to create a bridge among two or more wireless communications systems (standards).

- At the level of user terminal, which provide an interface to one or more wireless communication systems (standards).

While the interfaces at level of user terminals and base stations may be strongly related to the internal implementation provided by a manufacturer, the definition of the interfaces at the level of network infrastructure (gateways) could be an area for standardization.

Even if the promise of interoperability will be achieved, we still need to guarantee an adequate level of the protection of data exchanges among the various organizations involved in an emergency crisis. In most cases, this is sensitive data on public equipment, facilities or government property.
As a consequence, security is another area, which should be investigated in the standardization effort.

The following areas of security should be addressed in the standardization effort:

- The definition of the methods and interfaces to ensure the resilience and security of cognitive radio networks.
- Data protection, e.g. distributed in an ad-hoc or mesh RRS network.

6 General aspects of SDR and CR standardization

So far, most works in RRS have focused on cellular nodes and networks, as well as systems for public safety. This has been the consequence of the interests of the members of RRS. However, SDR and CR are general issues, which may very well reach beyond the networks studied.

In particular, there are three different areas also deserving some light in the present document:

- White Space in the UHF TV-bands.
- Cognitive Radio and consequences thereof.
- Regulatory Aspects.

6.1 White Space in the UHF TV-bands

At the end of 2008, FCC decided to open the possibility to use the "unused" parts of the UHF TV-bands resulting from the transition from analogue to digital TV transmission. "Unused" has two different interpretations: generally available bands, usually denoted Digital Dividend, and frequency bands available in time and/or location, usually called white space, see also clause 3.1.

The use of the "unused TV-bands" is based on a set of rules, utilizing both Digital Dividend and White Space, released by FCC. These rules were inspired by the standards being developed by IEEE 802.22, the rules may be regarded as standards. The bands are intended for broadband data, both fixed and personal/portable devices, however, different rules for fixed and portable equipment.

It should be noted that the FCC rules are quite specific for US conditions, as:

- unlicensed low power (< 1 W) devices are generally allowed;
- non-interfering, non-protected basis;
- channel availability is mainly based on geo-location and database, but also sensing e.g. for wireless microphones is mentioned;
- specific frequency allocations;
- Multiple device categories;
- FCC certification is mandatory.

This set of FCC rules gives a high protection for primary users, resulting in few available frequency channels for secondary users, in particular in highly populated areas! Thus market success is uncertain, as well as technical and spectrum (as interference) aspects are. Consequently, FCC has stated that the rules will be reviewed within 2 years.

In Europe, CEPT and EC have been active in intensive discussions for several years (with conferences, workshops, groups as ECC and RSPG) regarding similar possibilities for Europe. As a result of the World Radiocommunication Conference in 2007, the sub-band 790 MHz to 862 MHz has been reserved for mobile services, allocated for IMT services from the year 2015. If other parts of the UHF TV-bands should be used for wireless access, based on White Space concept then there is a timely need for standards in this particular area, as the FCC rules are not easily adaptable to Europe.

6.2 Cognitive Radio and consequences thereof

As mentioned in clause 4 of the present document, regulators have an interest to increase spectrum utilization, as some early measurements have indicated that the even though spectrum is a very valuable asset, it look as it is generally not used intensively in time and/or space. Firstly, it is concluded that there is a need for an agreed measurement methodology in order to get agreed data for spectrum use. Other users, secondary users, may be granted access to unused spectrum on specific conditions: marketwise (as "lease" for the spectrum), technical (spectrum bands, spectrum masks, modulations, etc.) and regulatory (partly similar to the technical requirements).

Generally, Cognitive Radio is seen as the technology for this kind of flexible use of spectrum. However, the full fledged Cognitive Radio encompasses technology in the far future, due to its high complexity. Consequently, in the close future further studies and research activities are needed. Once said studies will demonstrate feasibility and reliability of such technology, in a long term perspective, elaborated standards have to be developed accordingly.

Cognitive Radio requires some degree of flexibility, extended flexibility improves the "cognitive" performance. From this point of view SDR seems to be a likely platform for CR, but it is not a necessity - CR may be implemented without using SDR. Independent of platform, SDR or not, CR leads to requirements on the platform. These have to be defined, and most likely standardized.

6.3 Regulatory Aspects

The main regulatory issues, related to reconfigurable radio equipment, under discussion are:

- **Responsibility Issues:** In the case that a device does not operate within the regulatory framework, the responsibility relays within one single entity which needs to be easily identifiable.
- **Country-dependent Regulatory Framework Issues:** It has to be ensured that, after reconfiguration of a device, the regulatory framework of all concerned countries is met. This includes validation of equipment after post-deployment reconfiguration.

In particular, ETSI RRS has addressed the upper issues as follows:

- **Responsibility:** Building on TCAM (*Telecommunications Conformity Assessment and Market Surveillance Committee*) studies which propose two market models - horizontal and vertical markets:
  - **Vertical Markets:** All hardware and SDR software which is relevant for the declaration of conformity with the essential requirements for the intended use during the whole life cycle are controlled by one entity.
  - **Horizontal market:** Independent companies placing separately on the market hardware and SDR software (3rd party SW providers, etc.) which, when used together, are subject to the declaration of conformity with the essential requirements for the intended use of the equipment.
- **Country-dependent regulatory framework:** Issues arise if a post-sale reconfiguration of the SDR device affects the regulatory conformance in some/all countries. ETSI RRS provides generic standards which are applicable to any case of regulatory framework as illustrated in the examples below. Therefore, no specific recommendation is given for country-dependent regulatory framework issues:
  - **Example 1:** It typically is not an issue, if SDR SW updates of originally available standards are provided.
  - **Example 2:** It typically is an issue, if SDR SW updates are provided which add additional standards (such as WiMAX on top of an originally 3GPP standard, etc.).

7 Recommendations for Standardization

Based on the overall system architectures presented in clause 4 the following system aspects and interfaces may be considered as candidates for standardization (numbers refer to figure 5).

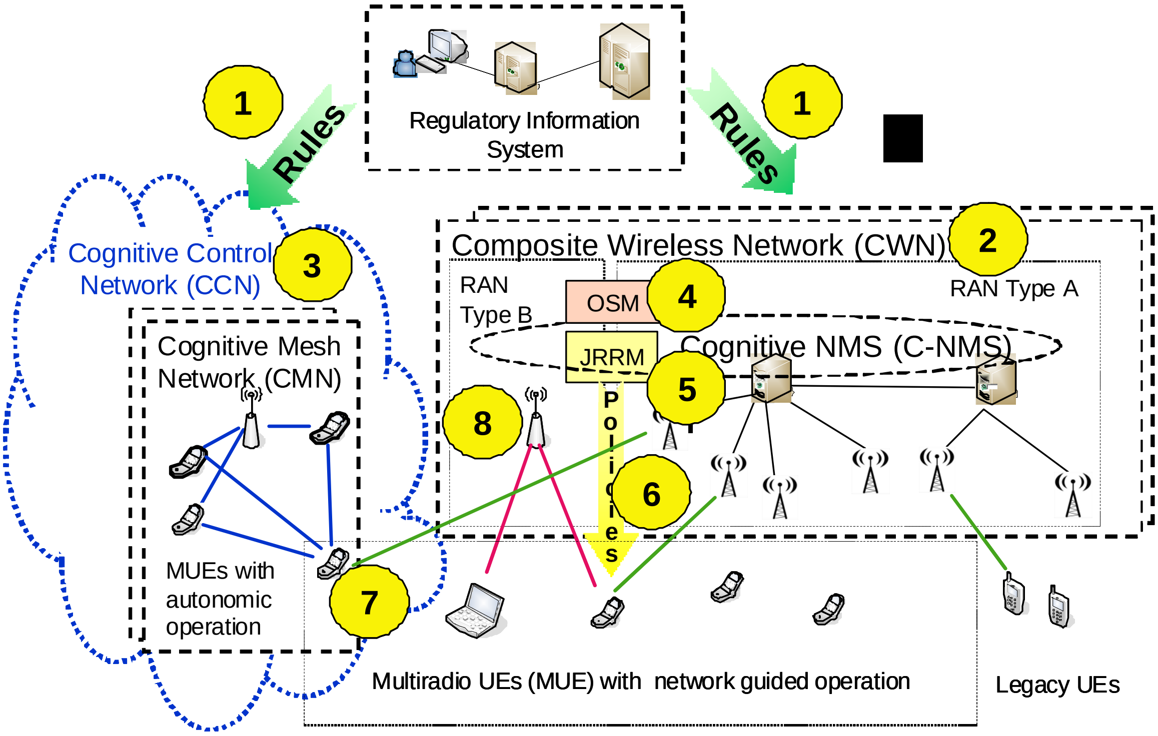

Figure 5: Candidate aspects for standardization

From figure 5 the following interfaces and areas are candidates for standardization:

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 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.

In this context it is essential to clarify the way of working for a committee as RRS. Most radiosystems standards, as GSM, WCDMA, LTE, TETRA, are carried out by a specific committee working vertically from e.g. OSI layer 1 to 7, defining radio interface, architecture, network, etc. The reconfigurable radio systems aspects (as SDR, CR), however, goes across these vertical standards, connecting two or more such standards in various points. Consequently, TC RRS will work horizontally, in close collaboration with the specific committees for each involved system. Only in exceptional cases will TC RRS involve itself in defining specific parameters as radio interface. In particular, TC RRS will not develop any vertical specifications for established systems (as GSM, TETRA, WCDMA, LTE) or their extensions.

7.1 Topics for standardization

For **SDR** it is recommended to standardize:

- SDR Reference Architecture Specification for Mobile Device.
- Specification of Multiradio Access Interface for Mobile Device.
- Specification of Unified Radio Application Interface for Mobile Device.
- Radio Programming Model and Interface Specification for Mobile Device.
- Specification of Reconfigurable RF Interface for Mobile Device.

For **Cognitive Radio, in particular Functional Architecture**, it is recommended to standardize:

- Functional architecture of reconfigurable radio systems, meaning the proposed functional blocks that are necessary for the management and control of radio resources in reconfigurable radio systems.
- Specification of interfaces among the FA functional blocks, so as to facilitate the production of the functional blocks by various vendors, intercommunicating through standardizes interfaces. It has to be noted that standardization in ETSI should focus on those interfaces which are not subject of standardization in other bodies.
- Specification of the protocol messages to be exchanged among the FA functional blocks.

For the Cognitive Pilot Channel, it is proposed to develop standards for:

- Definition and specification of physical and data link layer (L1 & L2) technologies and protocols for the out-band CPC in both downlink only and bidirectional operation. This should include the definition of the message structure and delivery procedures for cases like using the CPC concept for speeding up the start-up procedure in the context of a full DSA environment, for using the CPC as a support for secondary spectrum usage and for using the CPC as a support to radio resource management optimization.
- Definition and specification of message structure and delivery procedures for the in-band CPC for example to support radio resource usage optimization in the context of heterogeneous wireless environments.

In the area of Public Safety, it is recommended to:

- Define and specify system architecture of Cognitive Radio Networks in the Public Safety domain. This should include the definition of main functional blocks and interfaces. Security aspects like resilience of the Cognitive Radio Networks against security attacks should be included. The work should include the definition of the interfaces to exchange cognitive control messages.

Generally:

- To further liaise with CEPT and EC in order to develop standards for the white space in the UHF frequency TV-band.
- While the technical and regulatory conditions for devices using White Space in the TV-bands in Europe is still under study, it looks possible to develop technical solution elements for CR Systems, which may well have world-wide applicability and are therefore important for the European industry. Such solution elements have been identified by RRS as summarized in the present document.

History

Document history		
V1.1.1	October 2009	Publication