Which Regulation for Cognitive Radio? An Operator's Perspective

ISABELLE TARDY, OLE GRØNDALEN

Isabelle Tardy is Research Scientist in Sintef

Ole Grøndalen is Research Scientist in Telenor Corporate Development

Today, most of the prime radio frequencies are exclusively assigned for a number of years making it difficult to get access to new spectrum. Yet, measurements have repeatedly shown that at any location at any time a large portion of the spectrum is actually not used. From a regulatory and political point of view the underutilization of spectrum is hardly acceptable. Politicians argue for more competition and better telecommunication services for the public. Users want a lower threshold to broadband access, regardless of location. Conversely, operators' networks suffer capacity limitations at times, particularly for an increasingly demanding mobile broadband offer, including indoor usage. Interest in more flexible, reconfigurable radio systems is fuelled by the rapidly growing demand for data traffic.

One of the means to achieve a more efficient utilization of spectrum and therefore decreasing the cost per delivered bit is Cognitive Radio (CR), which relies on the opportunistic use of frequency voids. A number of regulatory bodies are promoting a more liberalized use of spectrum that would also encompass a more dynamic usage. This trend is also reflected in several standardisation forums that develop methods enabling a more flexible and highly dynamic spectrum usage.

The roadmap for CR and particularly how it will be brought to the market is difficult to assert, but large international efforts are under way to achieve a first consensus in the World Radio Conference in 2012. Regulatory questions include licensing regimes, enforcement of the regulations and agreement possibilities between actors, to name a few. This will give a frame for CR and the very role of actors and regulatory bodies could be reshaped in the process.

Two European research projects, SENDORA and QoSMOS, have supported the study of how to implement such CR systems, what would the different actors gain as well as the potential threats. Possibilities for cost optimization but also new opportunities such as micro-trading of spectral resources between different actors have emerged. These projects have allowed shaping an early operator's strategy on CR that can be promoted in a number of different bodies, particularly the spectrum regulatory authorities.

1 Introduction

Most of the spectrum that is interesting to operators has already been exclusively assigned. This is particularly true for spectrum below 3 GHz, which can be used for providing mobile services and indoor coverage. This means that it is difficult for new operators to get access to spectrum and for existing operators to get access to more spectrum to meet an ever increasing demand for capacity. At the same time, measurements have shown that at any given time at any given location, large parts of the allocated spectrum are actually not used [2][3]. This combination of a large unsatisfied demand for spectrum and the current poor spectrum utilization is unacceptable from a regulatory and political point of view. It indicates that there is a potential for offering the public better and cheaper wireless telecommunication services. Not utilized spectrum can be used by a new operator to offer services competing with existing services to enhance the competition in the market and hence reduce prices. Or it can be used by new operators to offer new types of services or by existing operators to enhance their existing services.

Cognitive Radio (CR) is a concept that has attracted much attention as a candidate for increasing the utilization of the spectrum resources. CR is an intelligent radio or radio system that obtains information about the spectrum usage in an area, eg. by using sensors for detecting radio activity, and then adapts its transmissions to both satisfy its own communication needs as well as ensuring that other radios or radio systems are not disturbed.

Such opportunistic use of spectrum voids, whether it is on a short-term or rather long-term basis, will allow for a globally more efficient use of spectrum, with expected benefits to all actors. For a mobile operator there are threats and new opportunities arising from such systems. The first threat for a mobile operator is that its spectrum – sometimes acquired at a high price – gets devalued because of unwanted interferences by a CR user, preventing to ensure a good, previously agreed QoS. Indeed it is not precluded that licensed spectrum be opened to new entrants, whose potential interference might be poorly controlled. Another danger is that other actors than

 ISSN 0085-7130 ©Telenor ASA 2010

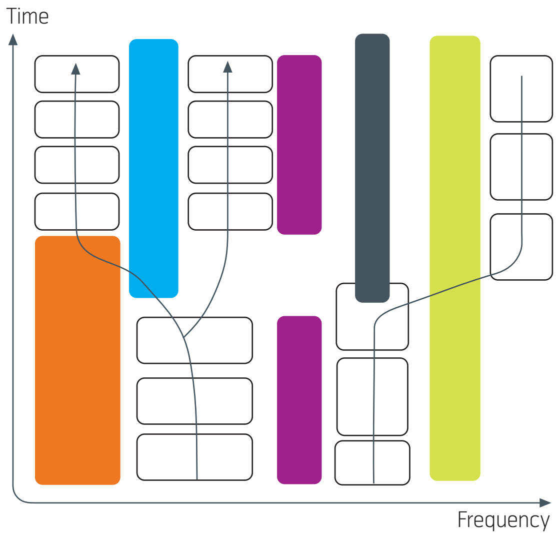

Figure 1 Available chunks of spectrum (white squares) are detected in frequency and time and can be aggregated for opportunistic use

traditional telcos start the business of offering a cheap, best effort broadband access with open systems in unlicensed bands, launching additional competition.

2 What is Cognitive Radio?

2.1 Main Principles

Cognitive Radio (CR) has been proposed as a way to increase the availability of spectrum resources. It is a system utilizing spectrum holes in licensed bands in an opportunistic manner. In order to implement this feature, a CR system functions along three basic steps further illustrated in Figure 1:

1 Detection of available spectrum from primary, licensed users;

2 Usage of this spectrum as secondary user;

3 Exit as quickly as possible if primary usage resumes.

A Cognitive Radio system is an ‘intelligent’ radio system that takes into account its knowledge about its environment and its communication needs and adapts its wireless transmissions in an optimal manner as illustrated in Figure 2.

2.2 Elements of CR Ecosystem

Several actors can be defined in a CR ecosystem. A simplified view is given in Figure 3 where users’, vendors’, operators’ and regulators’ benefits are highlighted. As for operators, both positive and negative consequences have been described. A better utilisation of spectrum is of course positive while mitigating interference from other actors, and increased competition will draw towards additional equipment costs.

Taking a deeper view into a CR ecosystem, one can define the following parties with associated ownership:

- End user of the communication applications;
- Owner of the licensed radio spectrum, eg. existing mobile telcos, TV broadcasters, public authorities or military organisations;
- CR operator that will utilize another’s radio spectrum, eg. as above but also new entrants;
- Regulatory body;
- Spectrum broker that can be either a regulatory body, an owner of the licensed spectrum or an independent third party;
- Owner of the fixed sensor network (if such a network is used);
- Vendor of equipment, including terminals with CR elements, sensors;
- System integrator.

A number of business and ecosystem related questions are still to be answered:

- Viable business models for Cognitive Radio;
- Spectrum sharing, trading or brokerage;
- Quantifying the increased efficiency in (own) spectrum usage;

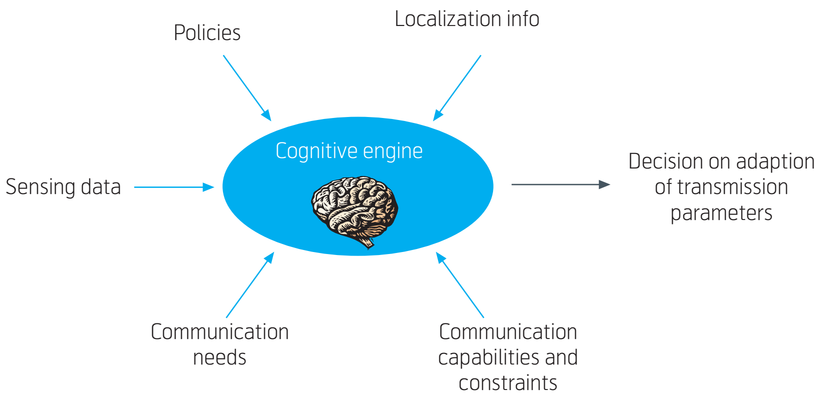

Figure 2 Cognitive operations needed for an optimal decision

ISSN 0085-7130 ©Telenor ASA 2010

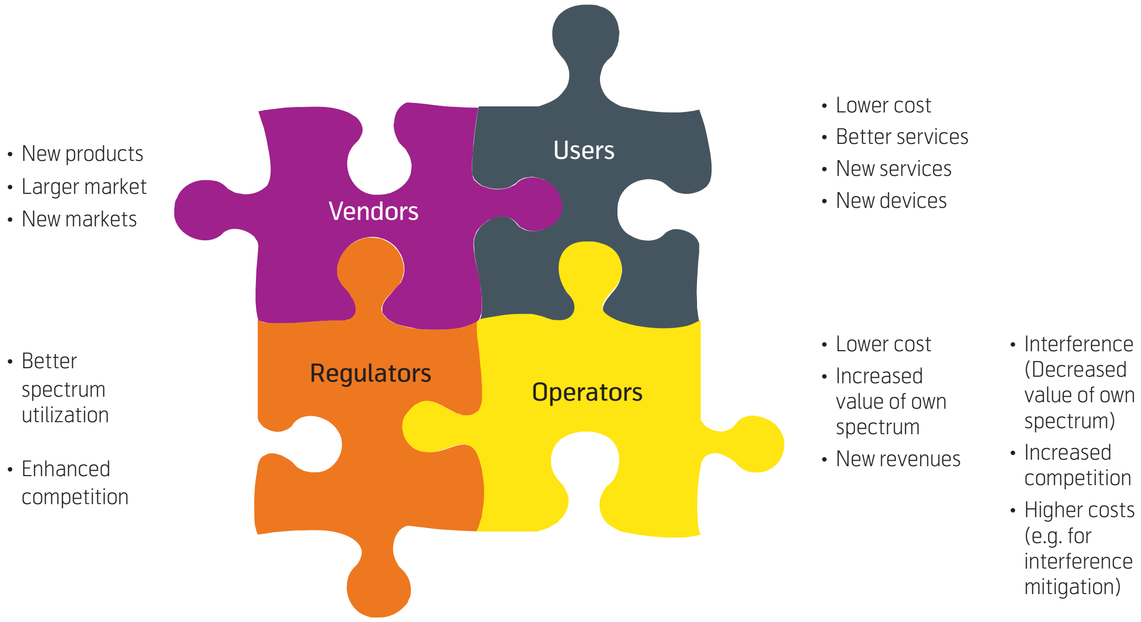

Figure 3 Some benefits and drawbacks of deploying CR and the consequences on a whole ecosystem

- Best level of operator cooperation and information exchange;
- Incentives/drives for operators.

2.3 What Are the Key Threats for an Existing Operator?

An obvious concern is the decreased value of the licensed spectrum where exclusive rights have been granted for years. If operators are forced to accept others using CR in an opportunistic manner, interference in their licensed spectrum will have two major consequences:

- The offer to the regular customers with a pre-agreed QoS may be compromised.
- In order to mitigate the effects, interference has to be known or detected and mitigation measures taken in due time.

New actors can use CR to fuel a new competition to operators by offering a cheaper, best-effort only service. Those can be in the form of extension of Wi-Fi or cellular networks that are outside the scope of telcos. This can be facilitated by a currently strong pressure from regulatory bodies to find solutions acceptable by all parties and facilitating both a wider access and developing (terminal) market.

Traditional telcos can also take advantage of CR by running a complementary, cheaper broadband access only where and when needed.

CR developments have started without operators that have been left out of the decision and development process. Therefore much of the research has been focused on ad hoc networking where operators have no business. Only recently, operators have been invited to discuss the applicability of CR in the frame of forums like ETSI. Some vendors realize that the volume potential can be maximized when collaborating with operators that have a large user footprint. Another interest is that CR developments can also be imported in traditionally licensed technologies like those of 3GPP.

3 Regulatory Roadmap for CR

3.1 Regulatory Trends on a Worldwide Basis

Developments in regulation include the fact that radio spectrum is moving towards technology and service neutrality. This means that in some bands, as for instance identified in WAPECS (Wireless Access Policy for Electronic Communication Services) [4] [5], the operators will be free to choose from any access technology, whether fixed or mobile as well as which service to offer, eg. whether mobile broadband or broadcasting. This should be done with minimal technical and regulatory constraints. This trend towards technology and service neutrality fits very well with the CR concept.

One of the main examples of underutilized frequency resources are the TV white spaces (TVWS). TVWS refers to frequencies which have been allocated to a broadcasting service, but which are not used locally.

ISSN 0085-7130 ©Telenor ASA 2010

The reason for not using a particular frequency in an area is to avoid interference problems. TVWS are the first bands identified for potential CR usage in the USA and Europe. In addition to representing large amounts of underutilized spectrum, the propagation properties at these frequencies are very favourable for providing indoor coverage and coverage in rural areas. Therefore much of the standardisation efforts focus on these bands.

3.2 Regulatory Work in ITU-R

In ITU-R the major milestone is expected to be the World Radio Conference in 2012. Agenda item 1.19 addresses specifically cognitive radio: "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)". A number of different groups are preparing for it, including Study Group 1, Working Party 1B. This group has the following tasks:

1 To review the definition for Software Defined Radio (SDR) and develop a draft common definition;

2 To develop a proposed definition for cognitive radio systems (CRS);

3 To discuss SDR and CRS related concepts, taking into account the work done in other Study Groups;

4 To identify potential regulatory issues associated with SDR and CRS.

Furthermore, WP 1B has issued the following statement: "SDR and CRS are technologies that may allow more efficient use of the spectrum by any number of radio communications, but are not radio communication services". In other words, CR can in principle be independent of service considerations and usual associated bands.

3.3 CEPT View on WRC2012 – Agenda 1.19

CEPT (European Conference of Postal and Telecommunications Administrations) came with the following statement: "Europe is of the view that frequencies or frequency bands for specific applications can be harmonised regionally by regional telecommunications organisations or on a world basis in ITU-R recommendations developed and approved in the normal way unless exception is justified."

During recent years, regulations have been developed according to specific principles such as flexibility in the access to spectrum resources, harmonisation of spectrum usage in Europe. Furthermore, standardisation is closed monitored and spectrum trading extended.

Flexibility of access to spectrum encompasses the technology and service neutrality paradigm, but with an effort to minimizing technical and regulatory constraints [1].

In CEPT a number of groups also tackle the question of CR:

- TG4: Digital dividend
- CPG PTA: Group preparing for WRC-2012
- SE42: WAPECS
- SE43: Compatibility, focusing on applicability of CR in the band 470-790 MHz

In WAPECS (Wireless Access Policy for Electronic Communication Services), the operators will be free to choose from any access technology and any service. The aim of SE42 group is therefore to establish a list of least restrictive technical conditions for the following frequency bands:

- 174 – 240 MHz
- 470 – 862 MHz
- 880 – 915 / 925 – 960 MHz
- 1710 – 1785 / 1805 – 1880 MHz
- 1900 – 1980 / 2010 – 2025 MHz
- 2500 – 2690 MHz
- 3.4 – 3.8 GHz

Higher bands, eg. up to 6 GHz could be envisaged as well, but it seems to be a more remote future. The prospect is however interesting as it would allow for more spectrum resources to be exploited, entailing more capacity to be potentially squeezed out. Indoor propagation is usually poor for frequencies above about 4 GHz, but for the systems deployed indoors CR would be a good option in the higher bandwidths.

The EU Commission has signalled particular interest for the first two bands where the principles of WAPECS would fit well. It has commissioned CEPT to lead further studies in order to identify the less restrictive conditions allowing flexible usage in these bands.

In the wake of deployment of digital television and resulting digital dividend, TV white spaces (TVWS) have appeared and given rise to speculations on how to use the new bands. Given that some of the television MUXes are used regionally, there will be frequency voids on a regional basis.

SE 43 is specifically looking at the best usage of CR in one of the most popular TVWS, the 470-790 MHz band. SE 43 terms of reference are "Define technical

ISSN 0085-7130 ©Telenor ASA 2010

and operational requirements for the operation of cognitive radio systems in the white space of the UHF broadcasting band (470 – 790 MHz) to ensure the protection of incumbent radio services/systems and investigate the consequential amount of spectrum potentially available as 'white space'".

It is envisioned that this band be the first to allow for CR operation in Europe, similarly to the 700 MHz band in the USA where FCC has ruled in favour of CR usage in March 2009. Certified equipment that will come first on the market could be in the TVWS, and CEPT wishes to encourage regulation in the band where this equipment will likely be available.

Authorisations are also moving towards less traditional individual rights of use where a license per operator is required. The number of allocations is expected to increase in the so-called general authorisation scheme with license-exempt or light-licensing regimes. If no license is required, the equipment will solely comply with a pre-defined set of regulatory conditions, eg. those entailed in IEEE 802.22 [6][7]. In the case of light licensing regime, the users of spectrum are to identify themselves and comply with the set of regulatory conditions.

Regulators have so far been in favour of letting the market decide on what is best to deploy, implying a lesser involvement of their part. Regulatory bodies envisage therefore the use of CR in a licence-exempt regime. The drawback with the licence-exempt usage is that the more users, the more interference. When users and their location are unknown, it is more difficult to identify the source of interference, let alone try to mitigate it or enforce a set of actions. Regulators have some monitoring stations that have been useful for licensed users, and long-term actions are launched when a problem (supposedly interference) is reported. In CR opportunistic use of spectrum is however expected on fairly small time scales and traditional monitoring stations would be of little help.

3.4 Radio Spectrum Policy Group

In October 2009 the European Commission, through its Radio Spectrum Policy Group (RSPG), published a report on TVWS [8]. The RSPG is a high-level advisory group that assists the European Commission in the development of radio spectrum policy.

This report:

- Defines and explains the terminology used (ie. Cognitive Radio systems, Software Defined Radio, etc);

- Provides an overview of various components of cognitive radio technologies (sensing the environment, information gathering, databases, cognitive pilot channel, learning capabilities, etc.) and a brief overview of the experiences and lessons in Europe and elsewhere with (pre-)cognitive technologies;

- Provides insight into the way in which cognitive radio technologies could operate in some models for spectrum management;

- Briefly summarises (as requested in the RSPG Work Programme) the USA framework for white spaces including the differences in the USA and EU regulatory framework, and possible actions to ensure timely regulatory responses in the EU;

- Identifies the challenging issues which require further attention.

In particular, it describes the regulatory frame that could be applied. Different forms of spectrum sharing can be envisaged, ie. so-called vertical or horizontal sharing where either all actors are equal (typically in a license-exempt environment) or spectrum can be taken or loaned by a second actor.

GSMA Europe is the European interest group of the GSM association, representing more than 170 operators. RSPG gave the GSMA the opportunity to comment their document, which they did late December 2009. In summary, the GSMA presented the following points:

- "Deployment scenarios for cognitive radio system should not be limited to opportunistic spectrum access but other scenarios such as the use of cognitive technology by an operator of a radio system to improve the management of its assigned spectrum resource or the use of the cognitive technology as an enabler for collaboration between the public land mobile networks and private networks.

- Impact of the features to obtain knowledge of the radio environment should be carefully analysed.

- Identification of regulatory requirements on deployment of CR devices will be necessary.

- Maturity of the solutions associated to the CR systems needs to be carefully estimated before deployment and should have to be preferably harmonised world widely. In particular, impact of possible interference as well as regulatory viability of the co-existence need to be carefully evaluated at the CEPT and ETSI levels (producing appropriate Harmonised Standards in accordance with the R&TTE Directive) in close cooperation with existing license holder.

ISSN 0085-7130 ©Telenor ASA 2010

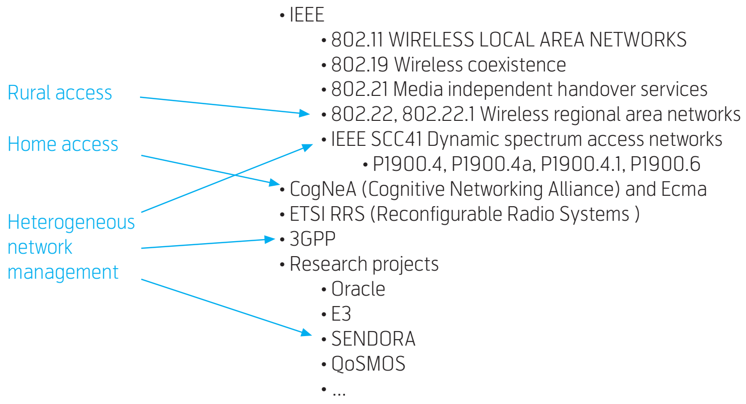

Figure 4 Relevant standards relative to CR in Europe and the USA

- CR systems should not be allowed to operate in licensed bands used by existing networks and infrastructures without the consent of the respective license holders."

The last point is critical for operators as licenses, sometimes acquired at a high price, have given the guarantee for exclusive usage, resulting in a controlled QoS offered to their customers. If this exclusivity is questioned, the same broadband quality might be more difficult to maintain.

4 International Standardisation Efforts

4.1 CR Standards and Other Useful Initiatives

A number of standards address CR usage. Most of them are in their infancy, defining use cases and environment while a couple have been actually defining PHY and MAC of CR systems. Relevant standards and some European research projects have been listed in Figure 4 with their associated applicability.

4.2 ETSI-RRS

ETSI Reconfigurable Radio Systems (RRS) Technical Committee (TC) has defined architectures for a base station and terminals that facilitate the use of Software Defined Radios (SDR). Some commonality with 1900.4 exists but complementarities are sought in order to avoid duplicating work.

The ETSI Technical Committee for Reconfigurable Radio Systems – TC RRS was created in 2008. Several reports have been published in 2009, see eg. ETSI TR 102 838 Reconfigurable Radio Systems (RRS); Summary of Feasibility Studies and Potential Standardization Topics.

ETSI-RRS is organized in four working groups as shown in Figure 5.

4.2.1 Architecture of Radio Base Stations (RBS)

ETSI RRS considers a basic architecture of Radio Base Station including the inherent requirements.

Generic Requirements

The generic requirements include, among others, the transition from one standard to another, multi-standard use, frequency re-farming, ability to participate in dynamic spectrum trading, secondary spectrum usage, dynamic capacity optimization depending on load, network planning and adaptation, antenna tuning, femtocell support, and backhaul reconfiguration.

Operator Requirements

The operator requirements include common management of two or more systems which coexist temporally and geographically, dynamic management of hardware resources dedicated to an existing system and to a new generation system. Changes in traffic over a day, congestions in a cell, OPEX and CAPEX reductions are the main objectives in this context. This common management is also planned to be directly linked with the network planning.

O&M Requirements

Re-configurability is considered to ease product logistics because of the expected reduction of product variants. RBS shall allow for SW upgrade of existing, as well as for capacity upgrade. Further requirements occur regarding RBS maintenance, test cases number, certification, reliability, and product roadmap management.

Based on these requirements, the following RBS architecture has been proposed:

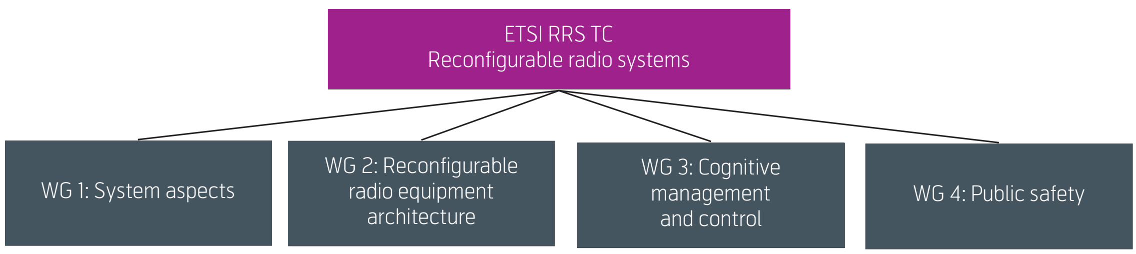

Figure 5 ETSI-RRS four working groups

ISSN 0085-7130 ©Telenor ASA 2010

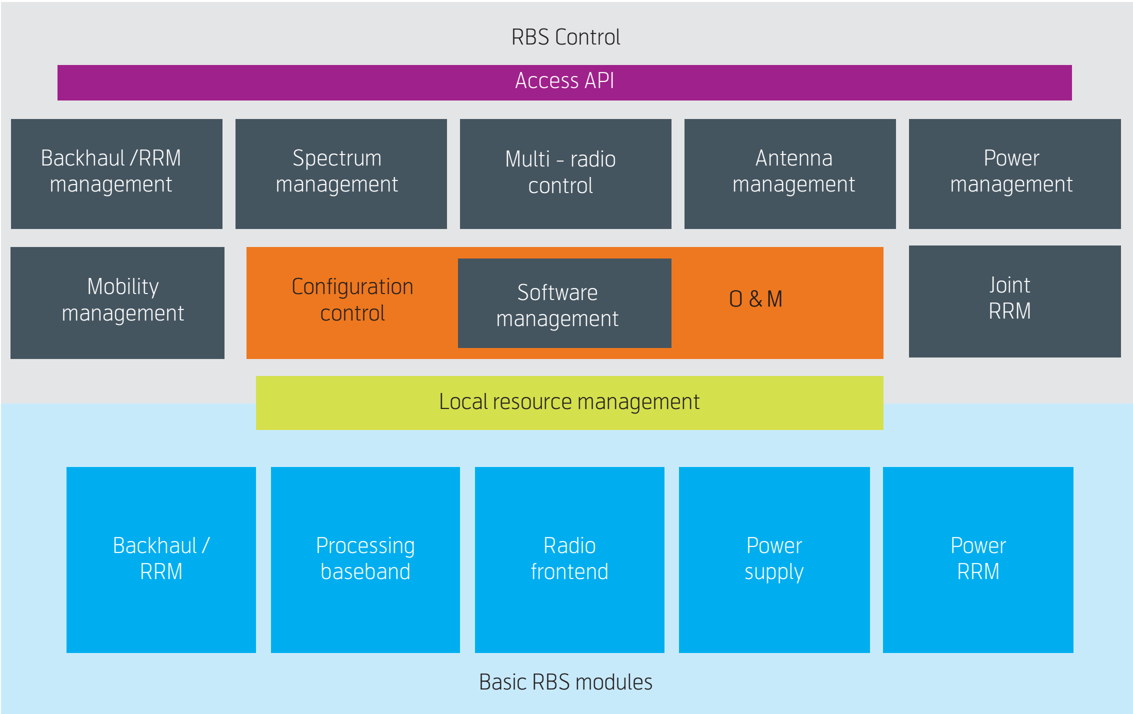

Figure 6 Reconfigurable architecture for radio base stations

4.2.2 Architecture of Mobile Devices (MDs)

ETSI RRS has identified a set of requirements including i) general architectural requirements, ii) capability requirements, iii) operational requirements, iv) interface requirements, and v) other requirements. The capability requirements are highlighted below:

a Multiradio configuration capability: SDR equipment in mobile device is expected to install, load and activate a radio application while already running a set of radio systems.

b Multiradio operation capability: SDR equipment in mobile device is expected to execute a number of radio systems simultaneously by taking into account temporal coexistence rules designed for their common operation.

c Multiradio resource sharing capability: SDR equipment in mobile device is expected to execute a number of radio systems simultaneously by sharing computation, memory, communications and RF circuitry resources available on the radio computer platform by using appropriate resource allocation, binding and scheduling mechanisms.

Taking these elements into account, ETSI-RRS has concluded on a possible functional architecture as shown in Figure 7.

The components of this framework have different responsibilities as follows:

a Configuration Manager (CM): (de)installation and (un)loading of radio applications into radio computer as well as management of and access to the radio parameters of those radio applications.

b Radio Connection Manager (RCM): (de)activation of radio applications according to user requests and overall management of user data flows, which can also be switched from one radio application to another.

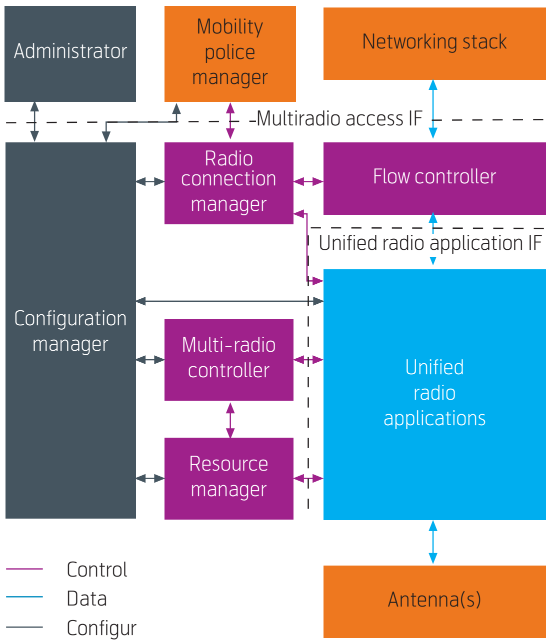

Figure 7 Functional architecture of SDR Equipment

ISSN 0085-7130 ©Telenor ASA 2010

c Flow Controller (FC): sending and receiving of user data packets and controlling the flow.

d Multiradio Controller (MRC): scheduling the requests on spectrum resources issued by concurrently executing radio applications in order to detect in advance the interoperability problems between them.

e Resource Manager (RM): management of radio computer resources in order to share them among simultaneously active radio applications, while guaranteeing their real-time requirements.

Currently, ETSI RRS is focusing on the definition of the inherent interfaces (Multiradio Access Interface, Unified Radio Application Interface) as highlighted above.

4.3 IEEE 802.22 / 802.11 / 802.19

802.22 – Wireless Regional Area Networks
The scope of this standard is to define the MAC and PHY layers, policies and procedures for operation in the TVWS. It includes some coexistence mechanisms and is intended for Wireless Regional Area Networks.

In the TVWS 470-790 MHz frequency bands, it will be required to ensure in particular a coexistence with television channels and PMSE devices such as wireless microphones.

The basic model is the following:

- Establishing a base station with associated mobile devices in a white space area;

- Not only protection of existing TV receivers in the vicinity but also avoiding false alarms in the sensors caused by propagation variations. A sub-group of 802.22 defines a beacon channel which reflects a very basic version of a Cognitive Pilot Channel (802.22.1).

In November 2009 the PAR has been modified in order to include nomadic and mobile usage; "point-to-multipoint WRANs, 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 objective was to prevent interference for IEEE 802.22 devices with low-power, licensed devices operating in television broadcast bands. The approach chosen has been the definition of protocols and data formats enabling the formation of a 'beaconing network'. In particular, it defines the MAC and PHY layers of IEEE 802.22.1 devices forming the beaconing network. Wireless Beacon Devices are expected to be mounted atop vehicles, mounted to the side of a building, etc. Minimum distances between beacon devices and wireless microphone receivers are given.

Beacon frame contents:

- The address & location of the originator of the beacon frame;

- Occupied TV channels;

- Security related status of the beacon frame;

- Parameter #1 (frame version, priority level, antenna parameters, etc.), Parameter #2 (TV channel width, cease transmission, time parity, …), Parameter #3 (antenna location, etc.).

This is similar to ETSI RRS' outband Cognitive Pilot Channel, but:

- Narrower in scope (ETSI RRS work goes far beyond IEEE 802.22.1, eg. in-band CPC, context exchange between neighbouring devices, uplink information flow, …);

- More detailed in implementation (MAC, PHY, security).

802.11 – Wireless Local Area Networks
There is new impetus in this group to move to White Space standardization. A new PAR was approved in Nov 2009.

Microsoft will probably contribute with its 'White-Fi' technology, otherwise known as KNOWS [9]. White-Fi is a new PHY and MAC of Wi-Fi-type, operating in WS.

This standard is likely to get much support because it will be based on the very successful Wi-Fi and it is strongly backed by Intel and Microsoft.

The question is whether it will be allowed in Europe and, if so, when this will happen.

802.19 – Wireless Coexistence
The 802.19 group investigates radio technology independent methods for coexistence among dissimilar or independently operated TV Band Device (TVBD) networks and dissimilar TVBD. It is useful for IEEE 802 Wireless Standards to effectively use TV White Space, but also for non IEEE 802 networks and TVBDs.

ISSN 0085-7130 ©Telenor ASA 2010

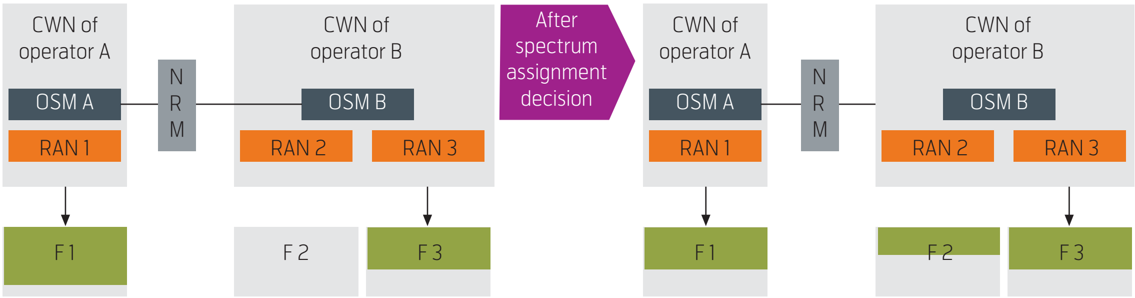

Figure 8 Example of configuration with a number of operators, Radio Access Networks and frequency bands resulting in a better utilization of capacity

The coexistence method consists of the following steps:

- Discovery (detect other secondary users; a network operating in WS must periodically check for new entrants, a new entrant must check before entering);
- Connection for coexistence between systems (Over-the-air versus backhaul debate for the communication between devices);
- Algorithms for adapting MAC/PHY parameters to enhance coexistence between networks.

Use cases presented in 802.19 are linked to the FCC use cases which pose different constraints depending on the transmission power (4 W, 4 W BS with 100 mW UEs, 100 mW, < 50 mW, < 40 mW).

- Campus deployment
- Congested apartment complex
- The home

This standard project addresses USA FCC TV White Space Rules. It may address the TV White Space rules of other regulatory domains. During the project lifetime, the draft standard may be modified to address any new or changing regulatory White Space Rules.

In November 2009 the study group was moved to a working group.

4.4 IEEE SCC41 P1900.4

The standard SCC41 *Standard for Architectural building blocks enabling network-device distributed decision making for optimized radio resource usage in heterogeneous wireless access networks* [SCC41] defines the building blocks for network resource management, device resource management and information between blocks. WG4 (also 1900-4) on Cognitive Spectrum Management is of special interest.

This standard published in March 2009 has the following scope:

- Management system that enables optimized radio resource usage in heterogeneous wireless access networks;
- Mechanisms for equipment reconfiguration on both network and terminal sides;
- Similar to ETSI RRS Functional Architecture.

The goal is to exploit information exchanged between network and mobile terminals, whether or not they support multiple links and dynamic spectrum access in order to improve the overall spectrum usage.

The standard defines the system and functional requirements, the functional architecture, together with information model and generic procedures.

Both Network Reconfiguration Management and Terminal Reconfiguration Management are considered. These management functions include the extraction of relevant physical parameters up in the protocol stack.

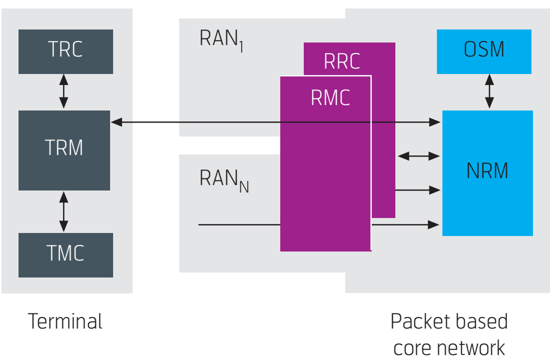

Figure 9 The IEEE 1900-4 system architecture

TRC = Terminal Reconfiguration Controller, TRM = Terminal Reconfiguration Manager, TMC = Terminal Measurement Collector, RAN = Radio Access Network, RRC = Radio Reconfiguration Controller, RMC = Radio Measurement Collector, NRM = Network Reconfiguration Manager, OSM = Operator Spectrum Manager

ISSN 0085-7130 ©Telenor ASA 2010

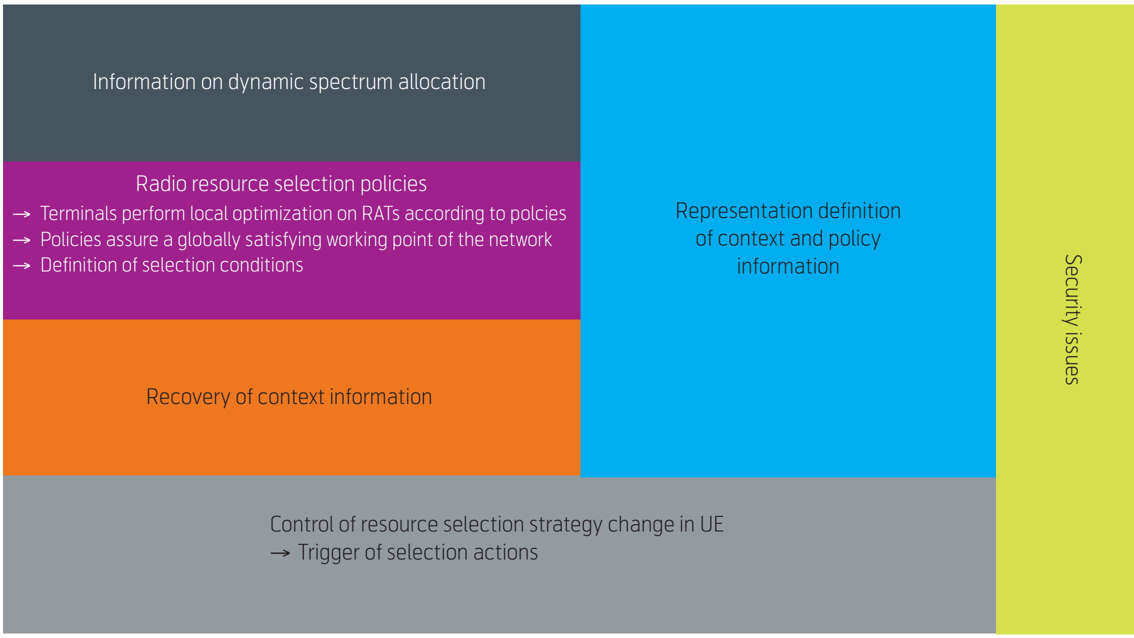

Figure 10 The Network Reconfiguration Manager in SCC41 (1900-4)

In addition, SCC41 (P1900-4) comes with a functionality directly embedded in user terminals, called the Terminal Reconfiguration Manager, with functionality represented in Figure 10. The Terminal Reconfiguration Manager gives the terminal the possibility to directly report to the deciding entity (ie. Network Reconfiguration manager) without going through a base station. This might be helpful in ad hoc networking where the terminal has to be most self standing. In addition, the terminal can report on more accurate status in its immediate vicinity and complement other measurements a Network Reconfiguration Manager might have.

The standard also describes functions inside the different boxes of Figure 11 and the procedures and related signalling from one entity to the other.

Note that broadcast systems intrinsically do not have a return channel. Possible signalling of network status or terminal environment should be transported on an additional channel. A potential multilink scenario must be interrogated after establishing the first detected two-way communications link.

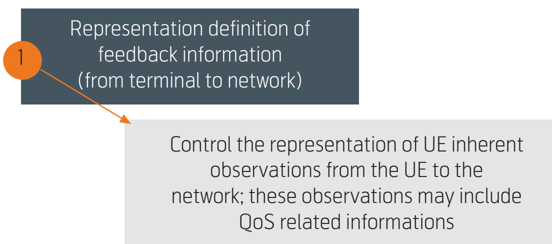

Figure 11 The Terminal (UE) Configuration Manager in SCC41 (1900-4)

4.5 Cognitive Radio Relevant Standardization in 3GPP

3GPP is undergoing continuous progress where flexibility is of primary importance. One of the tools is the self organising features that hold the promise of decreasing operating costs.

Self Organizing networks have several features that will be of interest in the context of CR, such as

- Adaptation/optimization;
- Self-healing (if one BS goes down the neighbouring ones will increase power to try to provide the same coverage as before);
- Inter-cell interference management where the UE will report to eNB. Varying power levels between eNBs will be decided, eg. to reduce interference to edge cell users.

In the adaptation/optimization, the adaptation is fairly mature. But this feature is not yet standardized; only at the stage of discussions between vendors. Status is similar for the self-healing feature.

Releases 8&9 allow for hard HO but buffering data from one BS to a second BS.

Release10 (LTE-advanced) adds several possibilities such as:

- Coordinated multipoint: two BSes can send traffic to a single UE.

ISSN 0085-7130 ©Telenor ASA 2010

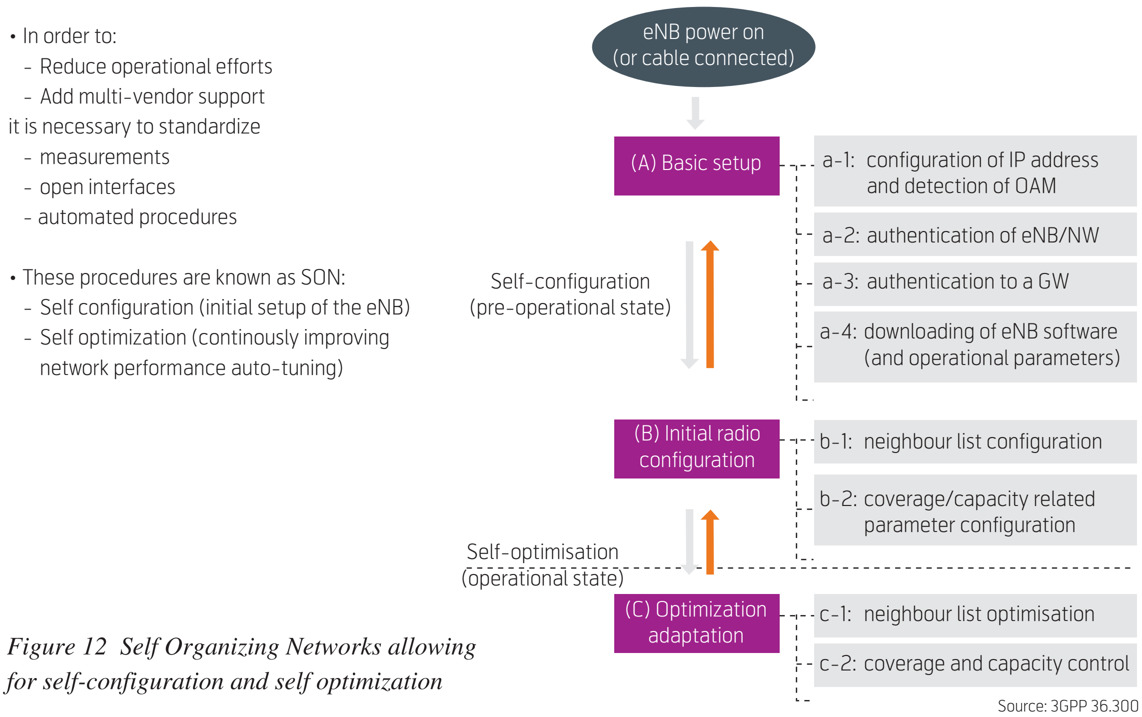

Figure 12 Self Organizing Networks allowing for self-configuration and self optimization

- Same content (as in an SFN), which is equivalent to macro diversity.
- Two different contents or at least two data streams.

The 3GPP's Access Network Discovery and Selection Function (ANDSF) contains data management and control functionality necessary for providing network discovery and selection assistance data to the User Equipment (UE, mobile station, MS) as per operators' policy. The ANDSF is able to initiate data transfer to the UE based on network triggers, and respond to requests from the UE. The ANDSF is located in the subscriber's home operator network and the information to access it should be either configured on the UE or discovered by other means. This function is similar to that of IEEE 802.21 Media Independent Handover (MIH) that allows for vertical handover between two different technologies.

Both ANDSF and MIH contain functionalities that can further be exploited for CR purposes instead of handover. Therefore it is foreseen that some of these functions may be reused in the management of CR equipment, at the terminal or the base stations side, or both.

4.6 CogNeA ECMA

ECMA International TC48-TG1 is a MAC/PHY standard project for operation in the TVWS which includes coexistence mechanisms.

The standard is intended to serve a broad range of applications, including

- Internet access for communities, and
- In-home High Definition Multi-Media networking and distribution.

The Alliance has already completed the steps of defining

- Marketing Requirements Document
- Technical Requirements Document
- Technical Specification.

Members include ETRI, HP, Philips, Samsung Electro-Mechanics, Georgia Electronic Design Center (GEDC) at Georgia Institute of Technology and Motorola. New members are currently joining.

5 Requirements and Constraints for CR Operations

5.1 As a Primary Operator: Limited Interference, Enforcement

Clearly, a CR system should not cause harmful interference into licensed systems under normal CR operation. However, if interference occurs, eg. due to malfunctioning equipment, the following requirements should be satisfied:

- The interference should be easy to identify.
- The responsible party causing the interference should be easy to identify.

ISSN 0085-7130 ©Telenor ASA 2010

- There must be a quick and reliable way for the operator to stop the interference.

Since CR by nature is a frequency agile system, interference from CR might be difficult to detect. Hence, if a primary system starts experiencing reduced performance it can be difficult to determine if this is due to interference from a CR system or to some other problem. In order to be able to identify a malfunctioning CR system quickly, the CR system must have mechanisms that make it easy to identify such interference.

Then, if a primary system detects harmful interference from a CR system it is important that the responsible party can be easily identified. This means that it must both be easy to detect exactly which CR network the interference is coming from, and which party or parties that are responsible for the CR and its operation.

Then when the affected primary operator contacts the CR operator, the CR system must have functionalities that make it possible for the CR operator to stop the interference. For example, if the interference comes from a malfunctioning terminal the system should have mechanisms for shutting down such terminals over the air. If that is not possible, it should be required that the CR operator is able to shut down the terminal in some other way, eg. by contacting the terminal owner by phone or by physically going to the place where the terminal is located.

In order for a primary operator to have confidence in these requirements being satisfied, the regulator should ensure that CR systems and operators have the necessary mechanisms and capabilities. In addition, it should be possible to hold a CR operator economically responsible for the damage of the interference cause to the business of the affected primary operator.

From this discussion it can be concluded that:

- CR operation should require an access network run by an operator;

- CR operation should require some kind of license.

5.2 As a Secondary Operator: Exit Strategy

As a secondary operator, CR usage implies that the voids are correctly detected and if primary usage resumes, the CR user must free the frequency/time slots. Exiting has to happen very fast in order to be unnoticed to the primary user. This is the exit strategy.

Current concerns include the actual ability to detect primary usage of spectrum within narrow time limits and with sufficiently high confidence, ie. how to detect vacant spectrum and its extension in space and time. The consequent interference management and capacity optimization is also under development and up to now only Best Effort types of services have been considered.

Detailed performance and functionality requirements for CR scenarios, eg.

- Service type
- Physical environment
- Range
- Mobility
- Terminal type
- Frequency of CR operation.

Other requirements related to deployment and operation, eg. easiness to deploy or how a CR system suits the rest of the networks will also have to be taken into consideration.

These requirements will also impact at least two other classes of requirements:

- Towards the system architecture;
- Towards the frequency pool manager.

Finally, radio hardware cost and performance issues need to be evaluated against each other. For instance, no Best Effort service should be offered with complex, expensive equipment.

6 European Projects SENDORA and QoSMOS

6.1 SENDORA – SEnsor Network for Dynamic and cOgnitive Radio Access

SENDORA is a European FP7 research project studying sensor network aided cognitive radio (www.sendora.eu).

The novel idea in SENDORA is to combine cognitive radio and sensor network technology. A SENDORA network consists of three main parts; a sensor network, a communication network and a fusion centre which connects the other two parts together as illustrated in Figure 13.

The sensor network consists of a network of fixed deployed sensors and sensors (or sensing capabilities) integrated in the user terminals. The sensors are used for estimating the utilization of different frequencies over a large frequency range (eg. 0 – 6 GHz). The measurements from the different sensors are sent to a fusion centre where they are combined and processed

ISSN 0085-7130 ©Telenor ASA 2010

to eg. estimate the geographical extension of spectrum holes.

The communication network consists of base stations and user terminals. Terminals can communicate with base stations to get connection to Internet. Terminals can also communicate directly with each other and form local ad hoc networks. In this case one of the terminals is appointed as a local fusion centre and denoted Cluster Head. The Cluster Head must communicate with the main fusion centre to exchange information and/or get instructions on how to behave.

The sensing network and communication network are functionally connected together by a fusion centre as illustrated in Figure 13. The fusion centre collects sensing information from the sensor network and estimates the spectrum usage situation in the area covered by the sensor network based on this information. The fusion centre also communicates with the communication network providing it with the information it needs to operate cognitively in an optimal way. The fusion centre might also act as the 'brain' in the communication network controlling the behavior of the secondary cognitive network, as well as the behavior of the sensor network

Figure 14 shows the architecture of SENDORA systems. The terminals in the architecture are marked with C, A and S according to their functional capabilities and H if they are local cluster heads, see table below.

The communication architecture consists of a centralized network of base stations through which the terminals can get Internet access, complemented by terminals communicating directly with each other forming local ad hoc networks. A centralized solution is an efficient way of implementing Internet access with predictable service (coverage, throughput, delay, etc.). Centralizing the intelligence and the sophisticated hardware also makes the use of low cost terminals possible.

Ad hoc communication between terminals located close to each other allows data to be transferred at higher bit rates and with less power than if the communication had to be transferred via base stations. Moreover, as terminals are close to each other, spectral opportunities will be higher in terms of capacity. In addition, thanks to ad hoc communication, the range and coverage of the secondary network can be extended by allowing terminals that are not able to access the centralized network directly to get access through nearby terminals with centralized access.

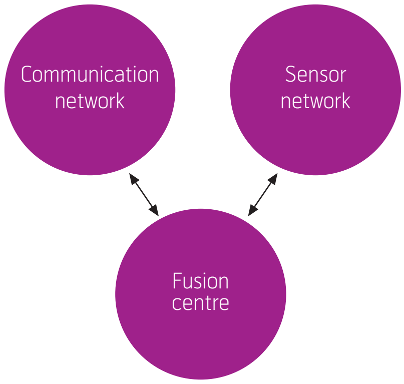

Figure 13 SENDORA main system components

At any given time, some terminals will communicate with the centralized network and some will be part of local ad hoc networks forming what might be conceived as *the centralized part* and *ad hoc parts* of the network. It must however be noted that the centralized network and ad hoc network change all the time as terminals change from ad hoc communication to centralized communication or vice versa.

The deployed network of fixed sensors, which is the main difference between the SENDORA concept and traditional cognitive radio, has three principal functions:

- **Accurate determination of the extension of spectrum holes**
  The deployed network of fixed sensors must be carefully planned so that it is able to determine the positions and spectrum usage of the primary users in an area with high accuracy.

- **Reliable detection of primary users starting to use the spectrum**
  The fixed sensor network must be able to quickly detect the presence of primary users starting to use the spectrum anywhere inside the area covered by the sensor network.

Centralized access (C)	The terminal has the properties needed to communicate with the base stations
Ad hoc (A)	The terminal has the properties required to establish and be part of an ad hoc network
Sensing (S)	The terminal has sensing capabilities
Cluster Head (H)	The terminal is the Cluster Head of a local ad hoc network

ISSN 0085-7130 ©Telenor ASA 2010

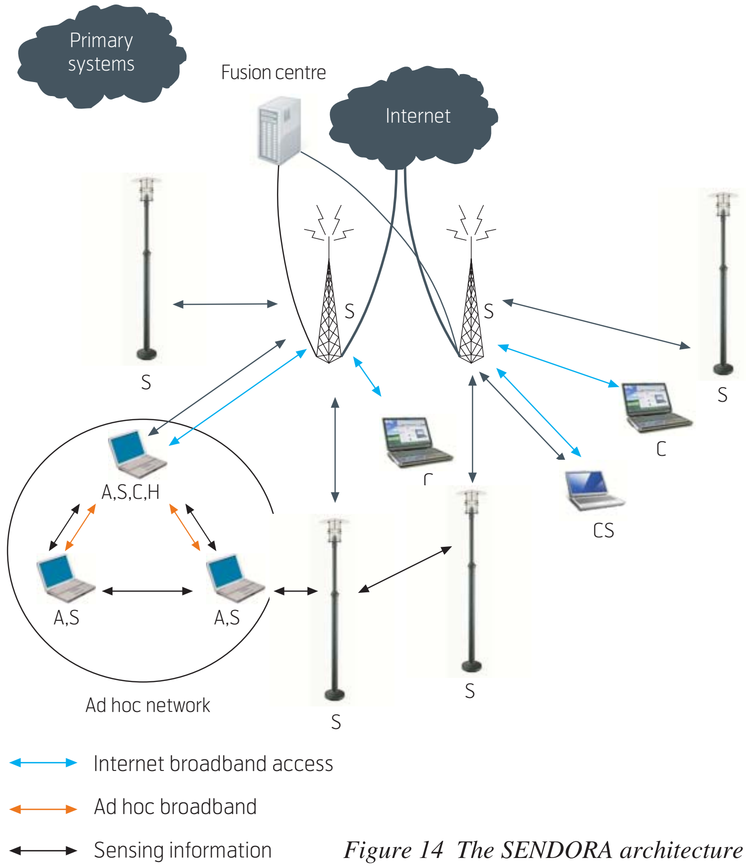

Figure 14 The SENDORA architecture

- **Enables tight control of the interference generated by the cognitive system**
  Traditionally, the interference generated by the cognitive radio network at different locations is predicted by using propagation models. Since the real values might be significantly higher than the predicted values, it is necessary to be very conservative when allocating maximum transmission power to the different cognitive terminals. But if a sensor network is used for measuring the actual interference levels at carefully chosen points in an area, this data can be used for calibrating the propagation models and enable much more accurate prediction of the interference level anywhere in the given area. The result is increased capacity for the cognitive radio system and reduced interference for the primary systems.

The owner of the cognitive communication and sensor networks might, but do not have to be the same entity. For example can the sensor network be owned and operated by the regulator which covers its expenses by taking a fee from the operators or users that use information from the sensor network. The sensor network could also be jointly owned by two or more operators that want to use the SENDORA approach to improve the utilization of their own spectrum or as a means to share their spectrum resources. Other ownership and operational arrangements are also possible, and some of these are studied in the project.

Preliminary results from the SENDORA project indicate that a sensor density in the order of 100 per km^2 is required. This means for example that to cover a city with an area of 400 km^2, about 40,000 sensors are required. Hence, deployment of a sensor network will represent a significant investment and the operating and maintenance costs will also be relatively high. Clearly, low cost sensors with low power consumption and large mean time between failures must be developed. Sensor technology is one of the topics that are studied in SENDORA.

6.2 QoSMOS – Quality of Service and MObility Driven Cognitive Radio Systems

QoSMOS is a European FP7 project studying QoS and Mobility-driven cOgnitive radio Systems. While SENDORA focuses on nomadic services, QoSMOS' focus is on mobile services and QoS, which introduces new challenges and possibilities, such as:

- More dynamic frequency situation when moving;
- Handover when spectrum is not dedicated;
- Handling of QoS when the frequency resource varies;
- The users can be placed in different parts of the frequency spectrum based on QoS class;
- QoS class can be input to the spectrum auction process.

The QoSMOS concept includes the use of two cognitive managers which operate on different timescales and amounts of radio resource. The lower one in Figure 15 is centralized and operates on a long timescale; it builds a portfolio of the available resources in a particular region. It manages a set of rules whose parameters can be initially programmed for different regulatory regimes. The upper one is distributed and operates on a shorter timescale, allocating spectrum to individual wireless links from the portfolio, also to a set of rules. Feedback flows from the upper one to the lower one to adjust and optimize the rules.

Although early examples of CR are focusing on TVWS, QoSMOS has decided to include TVWS and other bands, eg. WAPECS or military, as relevant for a number of different scenarios. In particular, WAPECS bands open for a more democratic usage of CR for users with equal rights than the current view that TVWS will exploit the bands not used by the broadcasters in a particular location.

QoSMOS is in the process of defining a limited number of scenarios. In addition, one sub-scenario would

ISSN 0085-7130 ©Telenor ASA 2010

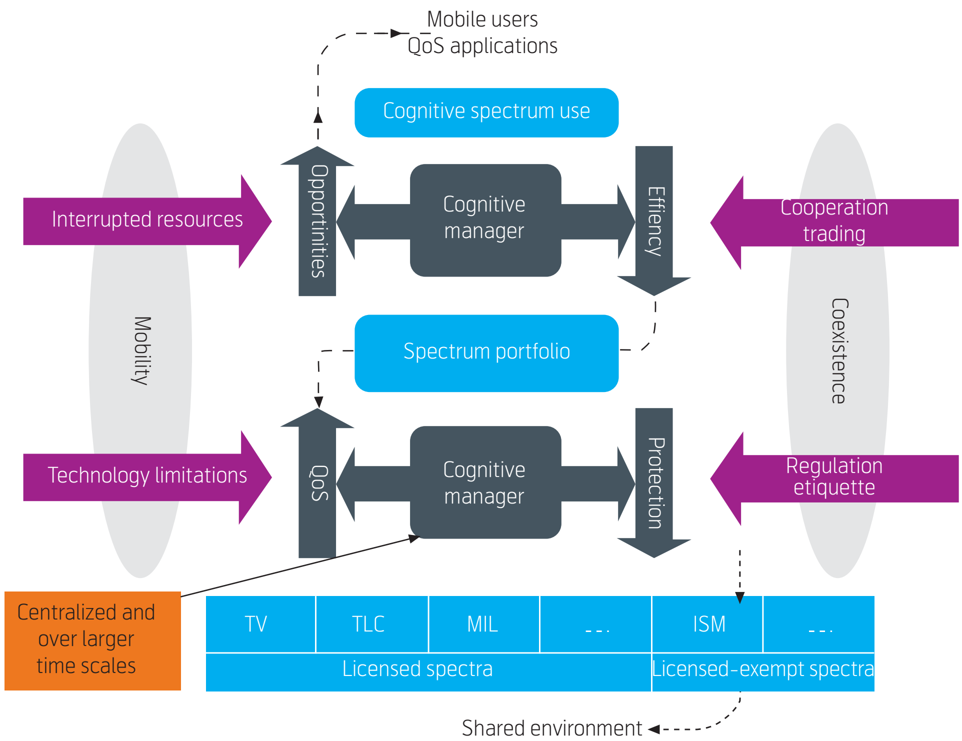

Figure 15 A generic QoSMOS CR engine with various constraints and functionalities

show some of the functionalities in the proof of concept that is within the lifetime of the project in 2012. A number of parameters are being defined and complemented by considerations on easiness to use or to deploy and commercial potentials. There is for the moment no ranking yet but these scenarios are being presented in EU and to QoSMOS External Board in order to collect feedback.

The initial use-cases for CR are

- The connected home
- Coverage of the street
- Smart metering
- Rural connectivity to buildings or clusters of buildings
- Cellular extension
- Public safety

The next steps in the QoSMOS project include

- For each chosen scenario, detailing of the specification requirements that will have an impact on the network topology;

- Development of a system architecture and finding the best balance between centralized and distributed architecture;

- Characterisation of the radio environment including sensing or database specifications and development of sensing technologies;

- Radio transceivers architectures;

- Optimization of spectrum utilization
  - Time-constraint optimization
  - Cognitive spectrum management, spectrum sharing etiquette
  - Management of interference from multiple cognitive terminals;

- Proof of concept;

- Business models;

- Input to standardization forums and regulatory bodies.

7 Conclusions

This paper has presented an innovative approach enabling broadband delivery by Cognitive Radio methods.

In mature markets, CR can help operators improve coverage and enhance services, particularly for frequencies with favourable propagation characteristics (eg. better indoor coverage). In emerging markets, CR systems can allow to offer broadband services at a lower cost.

Two European projects, SENDORA and QoSMOS, give a collaboration frame with vendors, operators and academia for building a better understanding of

ISSN 0085-7130 ©Telenor ASA 2010

the consequences of some technological choices as well as gain insight into the potential of different business models and regulatory regimes.

Operators, although latecomers in CR developments, are key to promoting technologies and allowing for a wider ecosystem. Operators' interests can be taken into account through regulatory bodies and major standardization forums like ETSI-RRS, IEEE 802.22, etc.

European countries typically have multiple cellular operators who are no longer able to differentiate themselves on coverage. Measures like infrastructure sharing that were unthinkable some years ago, are now being implemented in an attempt to significantly reduce costs. The same trend could be put on the radio system arena where sharing of spectrum, provided protecting rules are enforced, could allow for substantial benefits in the utilization of spectrum. Making possible alliances with other network operators is therefore key to CR commercial success.

Acknowledgements

The authors wish to thank our colleagues in Telenor and the other partners of SENDORA and QoSMOS for good collaboration, sharing of ideas, and jointly working together to develop cognitive radio technology.

References

1 Electronic Communication Committee (ECC) Report 80. *Enhancing harmonization and introducing flexibility in the spectrum regulatory framework*. 2009.

2 Erpek, T, Steadman, K, Jones, D. *Spectrum Occupancy Measurements: Dublin, Ireland, Collected On April 16-18, 2007*. Shared Spectrum Company Report, 2007 (available from http://www.sharedspectrum.com)

3 McHenry, M A, McCloskey, D. *Spectrum Occupancy Measurements: Chicago, Illinois, November 16-18, 2005*. Shared Spectrum Company Report, 2005 (available from http://www.sharedspectrum.com)

4 RSPG. *Opinion on Wireless Access Policy for Electronic Communications Services (WAPECS)*. November 23, 2005, RSPG05-102, (http://www.ilr.etat.lu/freq/docs/RSPG05-102.pdf)

5 CEPT. *Response to EC Mandate to Develop Least Restrictive Technical Conditions for Frequency Bands Addressed in the Context of WAPECS*. CEPT Rep. 019, Dec. 2007; (http://www.ero.dk/AF8F727A-BCD1-45A9-B454-59BD80A17BD1?frames=no&)

6 Stevenson, C et al. IEEE 802.22: The first cognitive radio wireless regional area network standard. *IEEE Commun. Magazine*, January 2009, pp. 130-138.

7 IEEE 802.22 Working Group on Wireless Regional Area Networks. http://www.ieee802.org/22/

8 Radio Spectrum Policy Group (RSPG) report on cognitive technologies. RSPG09-299. 11 February 2010. (http://rspg.ec.europa.eu/)

9 http://research.microsoft.com/en-us/projects/knows/

10 Sendora web site. http://www.sendora.eu

11 QoSMOS web site. http://www.ict-qosmos.eu

At the time of writing this article, Isabelle Tardy was with Telenor Corporate Development, working as a project leader and senior scientist on flexible wireless technologies for telecommunication. Her main responsibilities were within hybrid radio access networks that encompass always best connected, multillink and cognitive radio, network architecture, spectrum strategy and regulatory work, techno economy and standardization. Isabelle has been Telenor's representative in numerous European projects; i.a. principal investigator of the project QOSMOS, in spectrum regulation groups and in standardization fora like ETSI. Isabelle received the Engineering degree from FEPF, Sceaux, France, the Master of Science in Electrical Engineering (MSEE) from the University of Washington, Seattle, USA in 1990, and the Doctorat degree from Bordeaux University, France in 1995. From 1991 to 1998 she was with EADS Toulouse, France before joining Telenor in 1998. She has recently joined Sintef and continues her involvement in network architectures for multilink and cognitive radio solutions.

email: isabelle.tardy@sintef.no

For a presentation of Ole Grøndalen, please turn to page 84.