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(2011)

Introduction to cognitive radio systems in the land mobile service

M Series

Mobile, radiodetermination, amateur and related satellite services

International Telecommunication Union

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REPORT ITU-R M.2225

Introduction to cognitive radio systems in the land mobile service

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1 Scope

This Report addresses the cognitive radio systems in the land mobile service (LMS) above 30 MHz (excluding international mobile telecommunications (IMT)). It provides a general description of cognitive radio systems addressing technical features and capabilities, potential benefits and technical challenges. It also describes a set of deployment scenarios.

2 Introduction

The continuing growth of traffic in mobile networks demands a more efficient use of the limited spectrum resources. Advancements in technology are enabling the development of radiocommunication systems that have the potential to use the radio resources much more dynamically and efficiently than legacy radiocommunication systems.

In this context, cognitive radio system (CRS) techniques may offer improved efficiency and additional flexibility to the spectrum use. A CRS is not a radiocommunication service, but rather a system that employs technology that in the future may be implemented in a wide range of applications in the land mobile service. It should be noted that any system of a radiocommunication service that uses CRS technology in a given frequency band will operate in accordance with the provisions of the Radio Regulations governing the use of that band.

Cognitive radio systems are a field of research with associated applications under study and trial. The implementation of CRS technology is likely to be realized on a gradual basis due to a number of challenges coupled with the current state of the technology. In addition, the implementation of CRS technology in bands in which land mobile systems can be deployed may introduce specific and unique challenges of a technical or operational nature.

As noted, this report contains general information on CRSs in the land mobile radio service. For CRSs as specifically applicable to IMT systems additional information may be found in Report ITU-R M.2242 "Cognitive radio systems specific for IMT systems".

3 Definitions and terminology

The following definitions and terms are used in the Report.

3.1 Definitions

Cognitive radio system (CRS): A radio system employing technology that allows the system to obtain knowledge of its operational and geographical environment, established policies and its internal state; to dynamically and autonomously adjust its operational parameters and protocols according to its obtained knowledge in order to achieve predefined objectives; and to learn from the results obtained (see Report ITU-R SM.2152).

Software-defined radio (SDR): A radio transmitter and/or receiver employing a technology that allows the RF operating parameters including, but not limited to, frequency range, modulation type, or output power to be set or altered by software, excluding changes to operating parameters which occur during the normal pre-installed and predetermined operation of a radio according to a system specification or standard (see Report ITU-R SM.2152).

3.2 Terminology

For the purpose of this Report, the following terms have the meanings given below. However, these terms do not necessarily apply for other purposes.

Node

Node refers to a generic network element (e.g. a base station, an access points, radio terminals, core network element) that is involved in the related network operations.

Policy

a) A set of rules governing the behaviour of a system.

b) A machine interpretable instantiation of policy as defined in (a).

NOTE 1 – Policies may originate from regulators, manufacturers, network and system operators. A policy may define, for example, waveforms, radio resource control, and power levels.

System users may also be able to define preferences as long as they are consistent with the operator and regulatory policies.

NOTE 2 – Policies are normally applied post manufacturing of the radio as a configuration to a specific service application.

NOTE 3 – b) recognizes that in some contexts the term "policy" is assumed to refer to machine-understandable policies.

TV white space

A portion of spectrum in a band allocated to the broadcasting service and used for television broadcasting that is identified by an administration as available for wireless communication at a given time in a given geographical area on a non-interfering and non-protected basis with regard to other services with a higher priority on a national basis.

3.3 Abbreviations

CCC Cognitive control channel

CPC	Cognitive pilot channel
CRS	Cognitive radio system
DFS	Dynamic frequency selection
ETSI	European Telecommunications Standards Institute
IMT	International mobile telecommunications
LMS	Land mobile service
PPDR	Public protection and disaster relief
QoS	Quality of Service
RAN	Radio access network
RAT	Radio access technology
RF	Radio frequency
RLAN	Radio local area network
SDR	Software defined radio
SINR	Signal to interference-plus-noise ratio
UHF	Ultra high frequency

4 General description of a cognitive radio system

A CRS is not a radiocommunication service, but a system that employs technology that can be implemented in a wide range of applications in the land mobile service.

A system in the land mobile service using CRS technology must operate in accordance with the Radio Regulations governing the use of a particular band, as is also the case for any system in the land mobile or in any other service.

The introduction and deployment of cognitive radio systems still requires further studies on the technical and operational issues.

The following sections describe the technical features, capabilities, potential benefits and technical challenges of cognitive radio systems in the land mobile service.

4.1 Technical features and capabilities

The three technical features (see Fig. 1) that characterize a CRS are as follows:

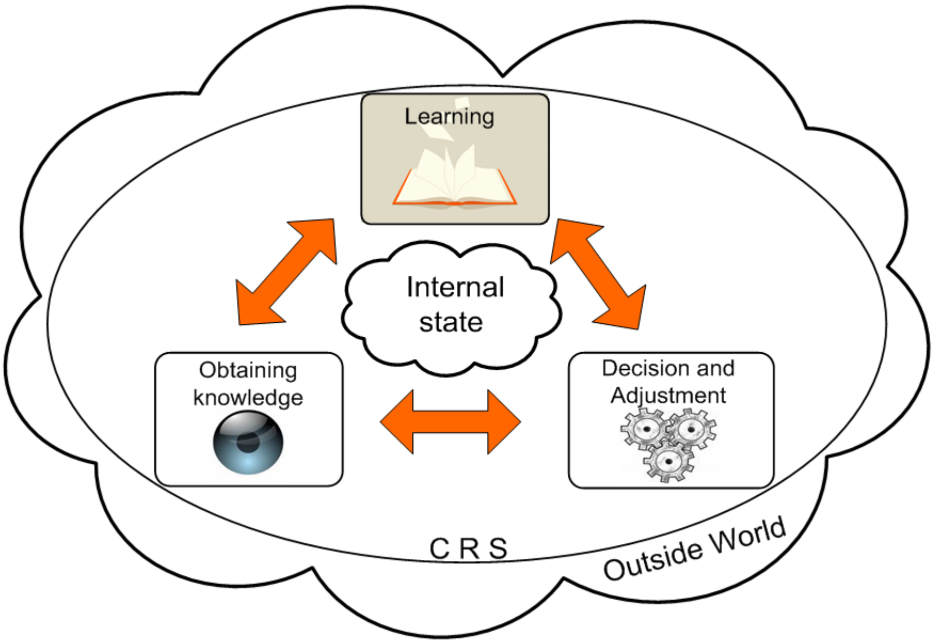
a) the capability to obtain the knowledge of its radio operational and geographical environment, its internal state, and the established policies, as well as to monitor usage patterns and users' preferences. This could be accomplished, for instance, by spectrum sensing, using a database, and/or receiving control and management information;

b) the capability to dynamically and autonomously adjust its operational parameters and protocols according to the knowledge in order to achieve predefined objectives, e.g. more efficient utilization of spectrum; and

c) the capability to learn from the results of its actions in order to further improve its performance.

FIGURE 1

Illustration of cognitive radio system concept



The features of a CRS represented here are described in §§ 4.1.1, 4.1.2, and 4.1.3.

Figure 1 presents the concept of cognitive radio system. The arrows in Fig. 1 represent the flow of information between the technical features of a CRS.

As an example the outside world includes information about radio environment, established policies, and users' preferences. The internal state, on the other hand, represents information such as traffic load distribution and transmission power levels. A CRS obtains information and monitors the outside world and its internal states and after pre-processing the information into knowledge uses it in the learning process as well as in the adjustment process.

The learning process compares obtained information to results of the previous decisions and also stores information to influence and optimize the future decisions. In order to maintain a continuous learning process, the information from decisions already made and adjustments and their success in the outside world are used. Several learning methods can be implemented, for example by generating new rules. Further the results of the learning contribute to obtaining knowledge. Learning can be facilitated via downloading policies and software that includes new logic for future decisions.

Decision making and adjustments are done using algorithms and policies based on the knowledge of the outside world and internal state of cognitive radio system as well as the information gained from the learning process of the past decisions and the extent of their success.

4.1.1 Obtaining knowledge

This feature of a CRS is the capability to obtain knowledge of the operational radio and geographical environments, the established policies and its internal state; and to monitor usage patterns and users' preferences along with any subsequent changes.

The CRS operational radio environment is characterized, for example, by the current status of spectrum usage, indications of existing radio systems and the assigned frequency and bandwidth, as well as coverage areas of these radio systems and interference levels.

The CRS operational geographical environment is characterized, for example, by the positions of the CRS and other radio systems nodes, by the orientation and characteristics of the CRS and other radio systems nodes antennas, and by distribution of users in the CRS coverage area.

The internal state of the CRS can be characterized by its configuration (e.g. frequency bands and protocols used by its CRS nodes), traffic load distribution and transmission power values, among other operational parameters.

Established policies may describe frequency bands allowed to be used by the CRS under certain conditions, where such conditions may include maximum level of transmission power in operating and adjacent frequency bands, and rules that CRS shall follow to avoid causing harmful interference in those bands.

Usage patterns may collect behavior of the CRS itself, other radio systems, and users. Users' needs for either high-speed access, fast download/upload time, low delay or cost versus performance may be described by user preferences and may be satisfied in accordance with the capability of the network.

This knowledge of a CRS may be about the system itself and its internal state including but not limited to:

- status of various nodes of the CRS (idle, in use, in maintenance, etc.);
- configuration of the CRS (e.g. frequency bands, bandwidth and protocols used by its CRS nodes);
- traffic load;
- interference level experienced by the CRS nodes;
- coverage area of the CRS;
- positions of the CRS nodes;
- characteristics and orientation of the CRS nodes antennas;
- transmission power levels of the CRS.

The knowledge may also be about elements external to the CRS including but not limited to:

- indication of other adjacent and co-frequency radio systems in operation in the vicinity of the CRS, their currently assigned operating frequencies and coverage areas;
- indication of current status of specific bands of spectrum;
- positions of nodes of other radio systems;
- users' preferences;
- established policies (see § 3.2) that may include e.g. frequency bands allowed to be used by CRS and under what conditions (such as maximum level of transmission power);
- Quality of Service (QoS);
- current status of spectrum usage;
- interference levels experienced by nodes of other radio systems;
- characteristics and orientation of other radio systems nodes antennas;
- distribution of users in the CRS coverage area.

In order to obtain knowledge, the CRS can use various approaches as proposed below. In addition, a combination of these approaches could be envisaged.

4.1.1.1 Radio link and network quality assessment

CRS nodes may monitor various parameters, which can be categorized to radio link quality characteristics such as received signal strength and signal to interference-plus-noise ratio (SINR) and network quality parameters such as traffic load, delay, jitter, packet loss, and connection drop/block statistics. The CRS nodes are aware of their current state, for example, frequency bands and RATs used by nodes, transmission power values, etc.

A CRS may also consider the application type, which may have an impact on the relevant quality parameters.

All this information, taken together, contributes significantly to the knowledge of the CRS.

4.1.1.2 Listening to a wireless control channel

Under this approach, a CRS node receives information transmitted on a predefined channel by a source internal or external to the system, such as a base station, or another CRS transmitter, giving for example, radio emission information, interference information, or indicating which operators, access technologies and frequencies are available at the geographic location of the CRS node.

Many approaches are being studied for this kind of channel. Two commonly envisioned approaches are cognitive pilot channel (CPC) and cognitive control channel (CCC) [1].

The CPC generally refers to a channel (logical or physical) that is used to regularly push information out to the CRS node. It can include the use of specifically transmitted messages, and having known transmission characteristics. The CPC can be used, among other things, to help a mobile terminal in identifying operators, policies and access technologies and their associated assigned frequencies in a given region. In some cases, when an uncoordinated deployed CRS base station (or Reconfigurable Base Stations) is booting up, CPC information may also be utilized to identify available spectrum in its current location.

The CCC is a distributed approach for real time communication between different CRS nodes in a specific geographical area. CCC may enable different CRS nodes to exchange information related to coexistence, generic spectrum usage rules or policies and/or specific capabilities and needs of different nodes. The information communicated on CCC may include, among other things, spectrum etiquette, rules for accessing specific bands, local availability of different bands, sensing information, available applications, or spectrum needs of different systems.

4.1.1.3 Spectrum sensing

Spectrum sensing allows CRS nodes to directly obtain knowledge of the radio environment including unused spectrum around them. Different detection methods to be used for spectrum sensing in a CRS have been proposed. These methods include, amongst others, matched filtering, energy and cyclostationary detection. In addition, cooperative sensing, which includes distributed cooperative spectrum sensing and centralized cooperative spectrum sensing, can also be used. Detection methods differ in their computational complexities and capabilities in detecting signals at different levels and at classifying these detected signals. The choice of a particular method versus another will depend on sensing requirements, signal level to be detected and computational resources available. It should be noted that there may be factors which prevent certain nodes from being sensed.

4.1.1.4 Geo-location

The locations of the CRS nodes (e.g. base stations and terminals) and other radio systems may be obtained using geo-location techniques similar to what other LMS systems use.

4.1.1.5 Database usage

In order to obtain knowledge, the CRS can access one or more data bases, which may contain information on what frequencies the CRS nodes can use at their current locations, which may be obtained using geo-location techniques and other possible information, such as allowed transmit power levels, time and duration of the availability of the frequencies, information on operational environment, the policies, usage patterns and user preferences.

4.1.1.6 Collaboration between CRS nodes and other different radio system nodes

The CRS nodes may share their obtained knowledge between each other. Additionally the CRS may obtain knowledge from other different radio system nodes e.g. about their geo-location, policies or usage patterns by exchanging information with them on a collaborative basis.

4.1.2 Decision making and adjustment of operational parameters and protocols

The second key feature of the CRS is its capability to dynamically and autonomously adjust its operational parameters and protocols according to the obtained knowledge and past experience, in order to achieve certain predefined objectives, such as to avoid harmful interference to other operational radio systems.

The CRS does not require user intervention in order to be adjustable. It may modify its operational parameters in real-time, in order, for example, to realize an appropriate communication quality, to change the radio access technology (RAT) to be used in a certain connection, to adjust the radio resources dedicated to a system, or to adjust a transmission power to reduce interference.

The CRS analyses the obtained knowledge and dynamically and autonomously makes decisions on its reconfiguration.

After the reconfiguration decisions have been made, the CRS changes its operational parameters and/or protocols according to these decisions.

The CRS nodes could change their operational parameters and/or protocols dynamically in response to control commands to do so.

The decision-making process of a CRS may involve understanding multiple users' preferences together with the radio operating environment and established policy in order to choose the proper configuration to support these users' preferences in concert.

The operational parameters that the CRS may modify include but are not limited to the following parameters:

– Output power
– Operating frequency
– Modulation type
– Radio access technology.

4.1.2.1 Decision methods

The CRS may make decisions in a centralized and/or distributed manner.

Centralized decision making may be considered for coordination of resources between CRS nodes in scenarios where global configuration and optimization are required and a central decision-making entity is deployed. The central entity collects a range of information from CRS nodes and makes a global optimization decision. This kind of centralized entity could be for example a network resources manager, or base station. The use of centralized decision making could assist a system in avoiding local sub-optimization and to use network and radio resources in the most effective manner possible.

The centralized architecture is simple and easy to control from a network operator point of view. However, when the number of CRS nodes increases, challenges could arise such as scalability, information exchange, processing capability and delay, etc.

The other method is a distributed decision making. A CRS may include a set of geographically distributed nodes, for example, multiple terminals and multiple base stations and/or access points. Within such a large heterogeneous CRS, it may cause difficulties to have only one single entity to make decisions on the CRS reconfiguration.

In another example, the CRS may be comprised of nodes communicating with each other using some kind of a mesh topology. Within such a CRS it may also be difficult to identify one centralized node making reconfiguration decisions.

In such cases, a CRS may require multiple management entities, to make decisions on its reconfiguration. Such a distributed decision making architecture could thus provide a scalable and more efficient management solution.

4.1.2.2 Adjustment methods

The CRS nodes may need to adjust various operational parameters (e.g. transmission power, carrier frequency and frequency band, radio access technology, etc.) and protocols by reconfiguration. Two possible examples to perform such reconfigurations are identified. One possibility is to use software defined radio (SDR) technology, which is mature and is currently widely used in radiocommunication systems.

Report ITU-R M.2117 provides more information on SDR techniques for radiocommunication systems in the scope of this Report.

Another possibility is to have corresponding hardware and software pre-installed in the CRS node. For example, a CRS node can have multiple hardware modules supporting different radio access technologies, frequencies, etc. Such a CRS node may dynamically decide which hardware modules will be used at a particular time.

4.1.3 Learning

The third key feature of a CRS is the capability to learn. The aim of the learning process is to enable performance improvement for the CRS by using stored information of its previous actions and their results. A CRS evaluates each action and routinely optimizes the parameters to further improve the performance (e.g. improve the capacity of the network). A key function of the learning process is to gather and maintain knowledge while operating in a changing radio environment and to potentially use this information in future transmissions. Furthermore, using this knowledge, decisions for dynamic adjustments can be made more appropriately and commands can be sent to CRS nodes in order to implement these decisions. In particular, the reliability and accuracy of the collected and stored information need to be ensured. The decision making and adjustment process described in § 4.1.2 may improve its performance by using the stored information when deciding on adjustment actions.

Many machine learning algorithms and models can be included in cognitive radio systems. According to available information and operational performance, the cognitive radio systems continue to train the existing algorithms and models, and this may enable cognitive radio systems to learn from the results of their actions.

4.2 Potential benefits

The demand for spectrum resources continues to rise due to issues such as an increasing level of Internet/data traffic and an ever-increasing demand for spectrum for mobile applications that require broader bandwidths. CRS technology may in the future be used as one method to address such problems by adding a level of flexibility as well as improving the efficiency of spectrum use.

CRS may provide several benefits to both system operators and end users, although the extent of these benefits and the suitability of applications using CRS techniques will depend on the frequency band.

4.2.1 Improving the efficiency of spectrum use

Improvements in the spectrum use efficiency could be based on approaches such as the improvement of the spectrum efficiency of the individual RATs or the improvement in the coexistence capabilities of these RATs.

It is expected that CRS capabilities could facilitate new coexistence possibilities such that land mobile systems may then be able to use frequency bands which are unused in a particular place at a particular time in an opportunistic manner. This method of spectrum utilization is expected to increase the capacity of the systems.

However, in order to maximize the benefit of deploying CRS elements several challenges need to be addressed; including, but not limited to, protection of existing systems, avoidance of interference, and the ability of radio systems that are required in disaster or emergency situations to promptly and securely access spectrum.

4.2.2 Additional flexibility

CRS capabilities can also facilitate the implementation of flexible approaches, including but not limited to improved flexibility of spectrum management, increased operational flexibility over the lifetime of fielded equipment and improved robustness or resiliency to failures.

4.2.3 Self-correction and fault tolerance

Fault tolerance has been a standard capability of communication systems for several decades. However, a CRS offers the potential of extending functionality beyond current practice.

In a CRS, multiple corrective strategies could be identified and the most appropriate based on likelihood of success be selected. Another benefit of such an approach to fault tolerance could be the ability of the CRS to learn patterns of failures and responses. These can be remembered and forwarded to other communication nodes within the network. The result is that a CRS may self-recover from a broad class of faults, experience less degradation from faults, and experience less down-time, until such faults are corrected.

4.2.4 Public protection and disaster relief (PPDR)

A land mobile system employing CRS technology, is a self-autonomous system that senses its environment, tracks changes, and reacts upon its findings. This brings a unique opportunity of deploying new communication systems in disaster stricken areas or in emergency situations. In such scenarios where the existing infrastructure is destroyed, malfunctioning or unavailable, the CRS can facilitate the re-establishment of the communication amongst PPDR personnel and other public officials in charge of responding to the disaster or emergency.

4.2.5 Additional power efficiency using CRS

CRS can be used to improve power efficiency by adjusting operating parameters, such as bandwidths or signal-processing algorithms based on application demands. For example location information can facilitate conservation of battery power of terminals. If a radio terminal is unable to operate in a particular area, it should conserve its battery power by not continuing to search for a network; rather, it should only try to reconnect when it is able to operate again and establish communication.

Awareness of the state of available energy sources (battery, fuel-cell, etc.) enables a CRS to vary its cognitive abilities in order to maximize the battery life. For example, with ancillary CRS abilities such as environmental and long-term spectral monitoring, message-relaying and collaborative sensing tasks could be deactivated as the energy sources are nearing depletion.

However, consideration about the additional tasks that need to be performed by the CRS before a transmission should also be included in the total power consumption of the device. Functions such as sensing, accessing to database or a CPC/CCC also consume power.

4.2.6 Potential new mobile communication applications

CRS could facilitate a wide variety of applications and solutions that utilize information and communication capabilities associated with time, location and frequency. CRS may enable discovery of locally available networks and applications. CRS could also enable sharing of obtained knowledge and other information with other local nodes. These capabilities could be utilized to develop a variety of presence and community networking applications.

4.3 Technical challenges

The full implementation of CRS technology by land mobile systems may need to progress on a step-by-step basis, due to a number of technical challenges in relation to the current state of the technology.

The implementation of CRS technology may introduce specific and unique challenges of technical or operational nature for each application and specific frequency band.

A list of such challenges include, for example:

– spectrum sensing techniques in relation to the reliability, accuracy and complexity of the different methods;
– the "hidden node" problem needs to be managed in order to guarantee the sensing reliability. This occurs when a CRS node cannot sense another node transmitting (for example, due to radio propagation conditions) or not sense the presence of a receive only node and therefore incorrectly assumes that the frequency channel is not in use;
– CPC and CCC deployment and robustness;
– database access mechanism and robustness (e.g. security, access method, the management responsibility, update rate);
– managing the situation when multiple CRS nodes attempt to access the same spectrum resources in an opportunistic manner;
– frequent or rapid modifications in the radio environment, geographical environment and the spectrum use by a CRS would have an impact on signaling overhead that needs to be evaluated and managed;
– coexistence between different CRS nodes and other radio nodes may require CRS solutions that are specific to a given deployment scenario;
– challenges related to the reconfiguration of operational parameters and protocols using software-defined radio technology which requires tuneable frequency operation.

5 Deployment scenarios

In the case of land mobile service, a CRS may be implemented in:

– frequency bands allocated exclusively to the mobile service; or
– frequency bands that have multiple radiocommunication service allocations.

The extent to which the deployment scenarios will be implemented depends upon compliance with national and ITU Radio Regulations.

The following possible scenarios for a CRS, which are not exhaustive, nor mutually exclusive, have been identified. Depending on the deployment scenario and the associated coexistence conditions, some technical or operational implications are to be considered and analysed, such as:

– the assessment of CRS deployment scenarios on band-by-band basis;

– the definition of appropriate technical conditions for CRS operation.

5.1 Use of CRS technology to guide reconfiguration of connections between terminals and multiple radio systems

In this scenario, multiple radio systems employing different radio access technologies are deployed on different frequencies to provide wireless access. Two possible examples of this scenario are identified.

In one example, some of the terminals are reconfigurable and can adjust their operational parameters and protocols to use different RATs. Such terminals can obtain knowledge required for these decisions and dynamically implement the adjustment. Also, radio systems may assist terminals in obtaining knowledge and guide terminals in their reconfiguration decisions (e.g. using CPC).

In another example, some terminals have the capability to communicate with the different radio systems, e.g. based on the subscriptions, but they cannot reconfigure their operational parameters and protocols to use different RATs. Additional multi-RAT nodes can be deployed to serve as a bridge between these terminals and the multiple radio systems. Such nodes can obtain knowledge about the operational environment, for example by discovering the nearby radio systems or terminals through sensing, and adjusting their own operational parameters and protocols to connect to the different radio systems and then act as a bridge to provide a connection to terminals that are not capable of reconfiguring to employ another RATs.

5.2 Use of CRS technology by an operator of a radiocommunication system to improve the management of its assigned spectrum resource

To illustrate this scenario, consider an operator who already owns a network and operates in its assigned spectrum and decides to deploy another network based on a new generation radio interface technology in the same or other assigned spectrum, covering the same geographical area. It is well-known that in certain geographical areas (e.g. a city), the traffic patterns may be non-uniform in time and in space. This may lead to a congestion situation (i.e. high blocking percentage of attempted communication) in some portions of the network in which the traffic is heavier (typically these portions are called hot-spots), while the other portions of that area may be characterized by lower blocking percentages since they are less loaded. Additionally, in the case of a deployment of two or more RATs in the same area, the traffic patterns to each deployed RAT could also be differently distributed in time and space.

Exploiting CRS capabilities, a network operator managing two or more RATs could utilize CRS technology to dynamically and jointly manage the resources of the deployed RATs, in order to adapt the network to the dynamic behavior of the traffic and to globally maximize the capacity. The network operator could e.g. reform the RAT’s of lower spectrum efficiency for utilization of higher spectrum efficiency RATs resulting in a less overloaded system.

5.3 Use of CRS technology as an enabler of cooperative spectrum access

In this scenario, information on spectrum use is exchanged amongst the systems in order to avoid mutual interference.

Two examples are identified for cooperative spectrum access.

Example one: there may be variations in the occupancy of the assigned spectrum in a specific location at a specific time. Thus, in order to improve the efficiency of the spectrum use, it may be possible to take advantage of parts of the unused spectrum resulting from these variations. The capability to predict these variations in advance or to exchange information amongst systems/networks on the usage of their respective assigned spectrum may allow operators to make agreements among them in order to share their respective assigned spectrum resources.

Example two: public land mobile networks deployed and managed by the operators, may coexist with private networks that in principle are deployed in an arbitrary manner by the end users. In this context, interference problems may occur between public land mobile networks and private networks, as well as, between multiple private networks due to the possible usage of the same spectrum bands and the interaction between macro-cells and femto-cells. In addition, traffic load-balancing between the public land mobile networks and private networks is another issue. CRS technology may allow cooperation between these networks to mitigate the interference and congestion issues.

5.4 Use of CRS technology as an enabler for opportunistic spectrum access in bands shared with other systems and services

Contrary to example one in § 5.3, this scenario has no "a priori" determination of the spectrum to be eventually accessed by the interested party. In this scenario the CRS may access parts of unused spectrum in bands shared with other radio systems and services without causing harmful interference. In this case, the selection of the spectrum to be eventually accessed is made on a real time basis following, amongst other things, a radio environment analysis.

For the opportunistic spectrum access the following examples have been identified:

Example one: the CRS could be an enabling technology for spectrum access in bands shared with other radio services. The actual use of spectrum by the radio systems of other radio services varies considerably, for example over time or geographic area. The CRS could identify the unused spectrum resulting from these variations based on a real-time radio environment analysis. Such identified spectrum could be used for different types of communication such as device-to-device communications.

Where permitted by the regulations that apply, cognitive capabilities may enable the systems to find opportunities to access the unused spectrum, meanwhile these capabilities also ensure there is no harmful interference to those radio services that should be protected. One case of this example would be the use of dynamic frequency selection (DFS) as a sensing method by radio local area network (RLAN) in the 5 GHz spectrum, in accordance with Recommendation ITU-R M.1652, to avoid interference to the radar systems.

Example two: the occupancy of the spectrum does not significantly vary over time so unused parts of the spectrum are available in a more static manner resulting from operational characteristics of systems of different radio services. The CRS can locate and utilize the unused parts of the spectrum through its capabilities. One case for this example would be the use of the unused portions of the ultra high frequency (UHF) broadcast band (i.e. TV white spaces) where one administration has recently allowed, and some others are considering to allow, license exempt devices to operate on a non-interfering and non-protected basis.

Example three: multiple radio systems employing CRS technology are deployed within the same band(s) and they can share the band(s) with each of the systems having equal access to the band(s). CRS technology provides technical solutions (e.g. a radio environment analysis is done via a centralized database) to facilitate co-existence between these systems at the same band, in order to resolve the possible contention and thus reduce the interference caused by the contention.

6 Conclusion

This Report outlines the current general understanding of cognitive radio systems in the LMS (excluding IMT). However, some findings in this report may be common to IMT systems.

As previously stated in this Report, CRS is not a radiocommunication service, but rather a system that employs technology that can be implemented in wide range of systems in the LMS. LMS systems employing CRS technology will operate in accordance with Radio Regulations like any other system.

An overview of the main technical features of a CRS is presented. They consist of three main capabilities: 1) obtaining knowledge, 2) decision making and adjustment and 3) learning. In particular, different methods to obtain knowledge are introduced as well as the general concepts of centralized and distributed decision making and adjustment methods.

The Report also addresses the potential benefits of CRS technology including a possible improvement in the efficiency of spectrum use and facilitation of additional flexibility.

The implementation of CRS technology may introduce challenges of technical or operational nature. These challenges could include implementation complexity, reliability of different methods for obtaining knowledge and interference avoidance.

This Report addresses four CRS deployment scenarios. Their implementation and feasibility will depend upon the resolution of technical challenges and compliance with national and ITU Radio Regulations. The current general understanding is that cognitive radio systems are a field of research activities and related issues have to be further studied. Therefore, at the time of publishing this Report, there is a need to continue ITU-R studies related to CRS technology in the LMS in response to Question ITU-R 241-1/5.

7 Related documents

7.1 ITU-R Recommendations

ITU-R M.1652 Dynamic frequency selection in wireless access systems including radio local area networks for the purpose of protecting the radiodetermination service in the 5 GHz band.

ITU-R F.1110 Adaptive radio systems for frequencies below about 30 MHz.

ITU-R F.1337 Frequency management of adaptive HF radio systems and networks using FMCW oblique-incidence sounding.

ITU-R F.1611 Prediction methods for adaptive HF system planning and operation.

ITU-R F.1778 Channel access requirements for HF adaptive systems in the fixed service.

ITU-R SM.1266 Adaptive MF/HF systems.

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7.2 ITU-R Reports

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ITU-R SM.2152 Definitions of software-defined radio (SDR) and cognitive radio system (CRS).

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7.3 Other references

[1] ETSI TR 102 802 V1.1.1, Technical report, ETSI Reconfigurable Radio systems (RRS), Cognitive Radio System Concept, Feb. 2010.