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ITU-R Standardization Activities on Cognitive Radio*

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SUMMARY Cognitive radio is an emerging technology to further improve the efficiency of spectrum use. Due to the nature of the technology, it has many facets, including its enabling technologies, its implementation issues and its regulatory implications. In ITU-R (International Telecommunications Union — Radiocommunication sector), cognitive radio systems are currently being studied so that ITU-R can have a clear picture on this new technology and its potential regulatory implications, from a viewpoint of global spectrum management. This paper introduces the recent results of the ITU-R studies on cognitive radio on both regulatory and technical aspects. This paper represents a personal opinion of the author, but not an official view of the ITU-R.

key words: *international telecommunication union -radiocommunication sector (ITU-R), cognitive radio, regulatory aspect, technical aspect, WRC-12*

1. Introduction

The radio frequency spectrum is a limited resource ranging from 9 kHz to 1000 GHz and the frequency range suitable for mobile communication is further limited, e.g. above some hundred MHz and below 6 GHz. The use of radio spectrum is globally governed by the ITU-R *Radio Regulations* (RR). The RR has been periodically updated to meet the demands for spectrum in the radio telecommunication market at that age. In recent years, the demand for radio spectrum for mobile communications continues to rise due to the prevalence of broadband internet access by mobile terminals such as smart phone. Consequently, it is very difficult to find radio spectrum to allocate to the mobile service. It is reported that some portions of the spectrum band may not fully be utilized at some time and at some place [1]. Cognitive radio is a promising approach to fully exploit these under-utilized portions of the spectrum.

ITU-R has been conducting the study on cognitive radio systems (CRS) since September 2006 under the Question ITU-R 241 from a technical and operational point of view. In November 2007, WRC-07 set up an agenda item for WRC-12 on cognitive radio and software defined radio to consider regulatory impact on the current international regulatory regime of spectrum. The result of the ITU-R study on regulatory impact in preparation for WRC-12 was completed and included in the CPM (the Conference Preparatory Meeting) Report. In November 2011, ITU-R further developed a report on cognitive radio systems in the land mobile service which contains the results of ITU-R's technical and operational study.

This paper first introduces the role of ITU-R and World Radiocommunication Conference (WRC) together with process for the revision of the RR in Sects. 2.1 and 2.2. In Sect. 2.3, WRC-12 agenda item on cognitive radio system is introduced with its background. In Chapter 3, ITU-R studies are overviewed. First, regulatory aspect is explained in Sect. 3.1 and thentechnical and operational aspects are introduced in Sect. 3.2. Chapter 4 concludes the paper.

2. ITU-R and WRC

2.1 ITU-R

ITU is a United Nations' specialized agency on telecommunication. ITU-R is a radio-communication sector of the ITU. The main mission of ITU-R is to ensure the rational, equitable, efficient and economical use of the radio frequency spectrum by all radio-communication services. For this purpose, ITU-R timely revises RR which defines international radio rules to globally manage the radio-frequency spectrum and satellite orbits, as well as develops *Recommendations* which are the international technical standards of radio communication as the results of ITU-R studies. The ITU-R Recommendation covers the use of radio communication service, the efficient use of the radio-frequency spectrum, radio communication systems and their networks and radio propagation, relating to terrestrial and satellite communications, broadcasting and space operation of radio communications.

2.2 WRC

World Radiocommunication Conferences (WRCs) are held every three to four years for revising the ITU-R RR. The RR has an allocation table of the radio frequency spectrum, by which international use of radio frequency spectrum is determined. Periodical update of the RR is required since the use of radio-frequency spectrum changes in time, e.g. recent rapid growth of wireless broadband mobile communications. ITU Member States review and determine their use of radio spectrum according to the updated RR.

Figure 1 shows an example of process for revising the RR. This example is the case of the WRC agenda on

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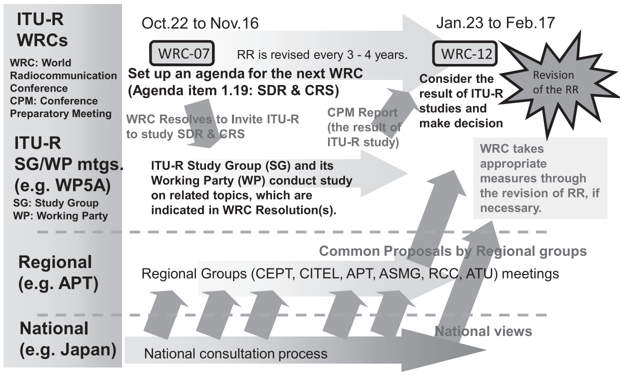

Fig. 1 Process to revise the radio regulations.

Cognitive Radio Systems, which was set at WRC-07 for the agenda at WRC-12. In the process, an agenda item relating to the revision of the RR on a particular issue should first be proposed to and discussed at the previous WRC. In the example, the agenda item was proposed and adopted at WRC-07. After setting up an agenda item for the next WRC, ITU-R studies start in ITU-R Study Groups (SGs) and/or their Working Parties (WPs), as shown in the second row in the figure. These studies are triggered by a WRC resolution, which invite ITU-R to study particular issues pertinent to the agenda item. The results of ITU-R studies are included in the CPM (the Conference Preparatory Meeting) Report. In parallel with ITU-R studies, ITU-R Member States or nations submit their views on the agenda item to their regional WRC preparatory meetings (e.g. APT Conference Preparatory Group Meetings in case of Asia-Pacific region). There are six regional groups pertinent to ITU-R WRC; APT (Asia-Pacific Telecommunity, CEPT (Conference Européenne des administration des Postes et des Télécommunications: European Conference of Postal and Telecommunications Administrations), CITEL (Comisión Interamericana de Telecomunicaciones: Inter-American Telecommunication Commission), ATU (African Telecommunications Union), ASMG (Arab Spectrum Management Group) and RCC (Regional Commonwealth in the field of Communications (a.k.a. Russian Group)). At the regional WRC preparatory meetings, the views of the members of the regional group are consolidated as regional views and are brought to ITU-R's WRC preparatory meeting (CPM: the Conference Preparatory Meeting) as well as to WRC-12 as regional common views and/or proposals. Each ITU-R Member State can also submit its own views directly to the WRC. In WRC, however, regional common views are more influential to the results of the WRC. In WRC, regional common views from various regions are further merged into common views across the regions. WRC considers the result of ITU-R studies and views expressed in the input contributions and finally make a decision on each WRC agenda item. All the necessary actions, such as new spectrum allocation and regulatory measures, are taken through the revision of the RR.

2.3 Agenda item 1.19 for WRC-12 on Cognitive Radio

WRC agenda item pertinent to cognitive radio was proposed at WRC-07 from CEPT and ASMG, separately as a European Common Proposal and Arab States Common Proposal. The European Common Proposal was a specific WRC agenda which was to consider spectrum requirements and a global allocation to support cognitive radio systems in the context of heterogeneous radio networks environment, based on the results of ITU-R studies, while an Arab States Common Proposal was a generic agenda which was to consider spectrum requirements and global allocation to support cognitive radio systems and/or radio software systems based on results of ITU-R studies. The European Common Proposal on Cognitive Radio had a background and purpose for a radio-frequency spectrum allocation to Cognitive Pilot Channel (CPC) [2] as excerpted below;

- Cognitive radio systems may cover a huge number of radio access technologies (RATs), that ought to be covered and be accessible in a heterogeneous cooperative reconfigurable radio system;
- Without any information about the location of RATs within the covered frequency range reachable from the mobile terminal (e.g. from 500 MHz up to 6 GHz), it will be necessary to scan the whole frequency range, which will result in a huge power and time consumption;
- It may be quite attractive to have a common harmonized physical radio channel (i.e. a common worldwide frequency band), a so-called cognition supporting pilot channel (CPC) to initiate the connection to the most appropriate network available to the user, at the time and location that the user wishes to establish a communication session;
- a CPC might require less than 50 kHz.

At WRC-07, these two regional proposals were considered and merged into a single agenda item for WRC-12 (WRC-12 Agenda Item 1.19) which was 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). The agenda for WRC-12 finally became an agenda to consider whether or not a new global regulatory framework beyond the current ITU-R RR is required for Software Defined Radio (SDR) and Cognitive Radio System (CRS), although original proposals from CEPT and ASMG sought for a new frequency-spectrum allocation for the Cognitive Radio System (CRS). Since there was no ITU-R definition on SDR and CRS, the WRC-07 decision was that the impact on the RR should first be clarified at WRC-12 taking into account the ITU-R study between WRC-07 and WRC-12 and take an appropriate actions, including the update of the RR if necessary and that a new frequency-spectrum allocation should only be considered after regulatory consideration.

The companion Resolution 956 invited ITU-R to study whether there is a need for regulatory measures related to the application of SDR and CRS technologies in time for WRC-12.

3. ITU-R Studies on Cognitive Radio

3.1 Regulatory Studies

In response to Resolution 956 (WRC-07), ITU-R started its study on SDR and CRS. The study on regulatory aspect was assigned to ITU-R Working Party 1B (WP1B), which handles spectrum management methodologies, as a responsible group for Agenda item 1.19 on SDR and CRS.

WP1B solicited views and information on SDR and CRS from concerned groups such as ITU-R Study Group (SG) 3 on radio propagation, SG4 on satellite services, SG5 on mobile services, SG6 on broadcasting services and SG7 on scientific services such as radio astronomy.

With an aid of SG5 WP5A which handles SDR and CRS technologies in the land mobile service, WP1B developed ITU-R definitions for CRS and SDR [3] as follows;
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,
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.

Based on these definitions, ITU-R WP1B further discussed in its meetings *to what the frequency-spectrum is assigned*, taking into account the current ITU regulatory framework and emerging technologies of SDR and CRS. WP1B concluded that (1) SDR and CRS are technologies that may allow more efficient use of the spectrum by any radio communication service defined in ITU-R RR but SDR and CRS are not radio communication services and (2) frequency allocations are made only to radio communication services or the radio astronomy services.

This conclusion implies that no frequency allocations can be made to CRS since CRS is a technology but not radio communication service.

Figure 2 shows the relationship of radio-communication services, systems and facilities including SDR and CRS [4], [5]. A set of facilities, for example hardware, software, antenna system, SDR and CRS, forms a radio communication system which is put to use for specific purposes in a radio communication service. Frequency spectrum is one of the facilities but the use of frequency spectrum is regulated through the *radiocommunication services*. The *radio-*

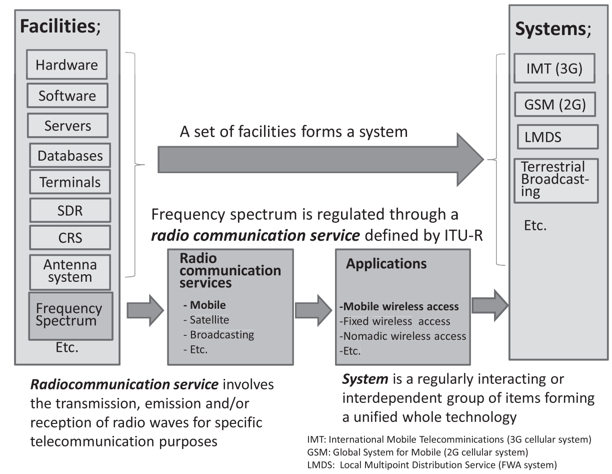

Fig. 2 Relationship of radio-communication services, systems and facilities.

communication service is defined by ITU-R as a service involving the transmission, emission and/or reception of radio waves for specific telecommunication purposes, e.g. mobile service and satellite service. It should be noted that *radio-communication services* are totally different from the *services* which are commonly used outside ITU-R and can be defined as a set of functions offered to a user by an organization, e.g. videophone, teleconferencing, e-mail. The international and national regulations are applied, regardless of the nature of the facilities used in the implementation of the radio communication systems. Since both CRS and frequency spectrum are items of the facilities, it is logically difficult to allocate frequency spectrum to CRS. Therefore, WP1B just confirmed that the frequency spectrum is only allocated to a radio communication service and used by a radio system in the radio communication service.

WP1B also received views on CRS from concerned groups within ITU-R. WP1B consolidated those views; (1) CRS technologies may offer improved efficiency to the overall spectrum use and provide additional flexibilities, and (2) CRS technologies can be used by any radio communication service. It was also unanimously agreed that any radio system that employs CRS technology shall operate in accordance with the provisions of the ITU-R RR. This implies that no change to the ITU-R RR is required when introducing CRS technologies into a radio system, i.e. there is no regulatory impact on the current regulatory framework of the ITU-R.

Some concerns were expressed with respect to the use of CRS technology to dynamically access the spectrum from "passive services", i.e. receive-only radio communication services in which radio stations do not emit radio waves. Radio station in the radio astronomy service (RAS) could be susceptive to interference from radio stations using CRS technology since the stations using CRS technology might misinterpret that the frequency-spectrum is available in the protected radio astronomy bands due to the lack of radio signal from the stations of passive services. In addition, the RAS increasingly use interference mitigation techniques which resemble CRS technology in a manner that the radio astronomy station senses spectrum to find a vacant spectrum available for reception of cosmic radio waves. In case of sharing with active services, some interference mitigation techniques used by the RAS rely on knowing the nature of the signals from active services. The mitigation techniques may be thwarted by the adaptability of modulation scheme and transmit power of CRS stations.

Concerns were also expressed by Earth exploration-satellite service satellite operators using passive sensors, e.g. for remote-sensing soil moisture, ocean salinity or sea surface temperature by receiving or measuring microwave radiation of natural resources. The measuring requires high sensitivity.

Fixed-satellite service (FSS) and broadcasting-satellite service (BSS) communities also expressed their concern. Dynamic frequency allocation (DSA) operation by using CRS technology in the FSS and BSS frequency bands needs to consider that (i) FSS or BSS terminals (earth stations) are deployed *ubiquitously* worldwide and many of them do not continuously transmit their signals or are receive-only terminals and that (ii) the downlink signal from satellites are very weak to detect it. These make it difficult for radio stations using DSA operation with CRS technology to detect or geolocate the FSS or BSS terminals. In case of using beacons for detection or geolocation, it is difficult to retro-fit beacons on a large number of existing FSS/BSS terminals. The use of database for FSS/BSS earth stations is impractical since many earth stations are temporarily and ubiquitously located and FSS/BSS operators would not want to disclose their users' sensitive data.

Despite the above concerns and technical challenges, ITU-R WP1B concluded that the capabilities of cognitive radio systems, particularly with devices querying a database in which parameters (such as locations, frequencies, regulations and policies, etc.) for protected stations are registered, not only have the potential to make more efficient use of spectrum, but to also offer more versatility and flexibility, through the increased ability to adapt their operations.

Taking into account the results of ITU-R studies on CRS, WP1B also developed three possible methods to conclude WRC-12 agenda item 1.19 (SDR and CRS) and ITU-R Conference Preparatory Meeting (CPM) finally approved these methods for information to WRC-12 as follows;

- **Method B1, Option A: No change to the ITU-R Radio Regulations.**
  Under this method, WRC-12 concludes no change to the ITU-R RR and no further action is taken by WRC-12. Technical and operational considerations related to the CRS technologies implemented in any systems of a radio communication service could be developed in ITU-R Recommendations and Reports as appropriate.
- **Method B1, Option B: No change to the Radio Regulations and develop an ITU-R Resolution providing guidance for further studies on CRS.**
  Under this method, WRC-12 concludes no change to the ITU-R RR. In addition, an ITU-R Resolution is developed at ITU-R Radio Assembly 2012 (RA-12) to provide a framework in order to facilitate studies on technical and operational considerations related to the implementation of CRS technologies to ensure coexistence. Sharing among radio communication services can be studied and its results can be addressed in ITU-R Recommendations and Reports as appropriate.
- **Method B2, Option B: Add a WRC Resolution providing guidance for further studies and guidance for the use of CRS and no other changes to the Radio Regulations.**
  Under this method, WRC-12 concludes no change to the provisions of the ITU-R RR but a WRC Resolution is developed to provide a framework for guidance of the studies on technical and operational considerations related to the CRS technologies implemented in any systems of a radio communication service leading to ITU-R Recommendations and Reports as appropriate as well as guidance to administration for use of the CRS. This method does not propose a new agenda item at the next conference after WRC-12.

Taking into account the results of the ITU-R studies and input contribution from APT, CEPT, CITEL and USA, RA-12, which was held in Geneva, Switzerland on 16th–January 20th, 2012, developed and approved a new ITU-R Resolution of studies on the implementation and use of cognitive radio systems (Resolution ITU-R 58). The resolution resolves to continue ITU-R technical and operational studies for the implementation and use of CRS in radiocommunication services, giving a particular attention to enhancing coexistence and sharing among radiocommunication services.

Considering the new Resolution ITU-R 58 from RA-12 and the above possible methods to conclude WRC-12 Agenda item 1.19, WRC-12, which was held in Geneva on 23rd January–17th February, 2012, concluded no change to the provisions of the Radio Regulations and no future agenda item on the frequency-spectrum for CRS at the next Conference, i.e. WRC-15. WRC-12 also developed a new WRC Recommendation [COM6/1] on deployment and use of cognitive radio systems, taking into account that the use of CRS does not exempt administrations from their obligations with regard to the protection of stations of other administrations operating in accordance with the Radio Regulations, since there was a strong concern at WRC-12 from some administrations on the potential cross-border interference between a system with a CRS technology, such as a DSA, in a radiocommunication service and other systems in other radiocommunication services. The WRC Recommendation recommends that administrations participate actively in the ITU-R studies to be conducted under Resolution ITU R 58, taking into account the above mentioned obligations.

3.2 Technical Studies

3.2.1 Cognitive Radio Systems in Land Mobile Service

ITU-R has been studying CRS in ITU-R WP5A which deals technical and operational studies of land mobile service, in accordance with ITU-R Question 241-1/5 (Study Question on CRS) before WRC-07. In ITU-R, the need to study CRS was recognized in the course of studying SDR and developing SDR Report (Report ITU-R M.2117). The ITU-R Question 241-1/5 included the following study items;

- What is the ITU definition of cognitive radio systems?
- What are the closely related radio technologies (e.g. smart radio, reconfigurable radio, policy-defined adaptive radio and their associated control mechanisms) and their functionalities that may be a part of cognitive radio systems?
- What key technical characteristics, requirements, performance and benefits are associated with the implementation of cognitive radio systems?
- What are the potential applications of cognitive radio systems and their impact on spectrum management?
- What are the operational implications (including privacy and authentication) of cognitive radio systems?
- What are the cognitive capabilities that could facilitate coexistence with existing systems in the mobile service and in other radiocommunication services, such as broadcast, mobile satellite or fixed?
- What spectrum-sharing techniques can be used to implement cognitive radio systems to ensure coexistence with other users?
- How can cognitive radio systems promote the efficient use of radio resources?

Based on the Question, ITU-R developed an ITU-R Report entitled "Introduction to cognitive radio systems in the land mobile service" [6]. This report introduces a concept of CRS and describes technical features, capabilities, potential benefits and technical challenges of cognitive radio systems in the land mobile service. The report also provides deployment scenarios of cognitive radio systems.

First, the report identifies three capabilities that characterize a CRS as shown in Fig. 3;

- 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 receiving control and management information;
- 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 utilisation of spectrum; and
- the capability to learn from the results of its actions in order to further improve its performance.

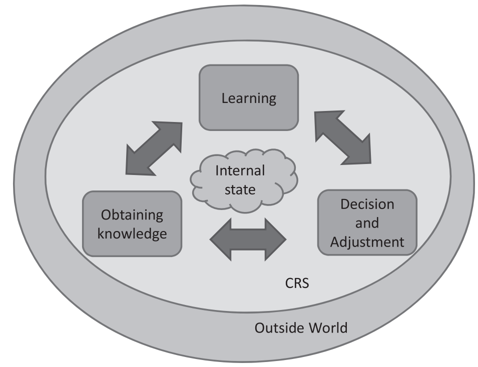

Fig. 3 Illustration of cognitive radio system concept. (The arrows in the figure represent the flow of information.)

The report further delineated obtaining knowledge, decision making and adjustment, and learning. Particularly, the report explains approaches to obtain knowledge since how to obtain knowledge is a key to successful detection of radio stations in use. The approaches include 1) *radio link and network quality assessment* including monitoring parameters such as received SINR (Signal to Interference-plus-Noise Ratio) in radio link and network load, delay and packet loss in the network, 2) *listening to a wireless control channel*, such as Cognitive Pilot Channel (CPC) and Cognitive Control Channel (CCC) [2], [7]–[9], 3) *spectrum sensing*, such as energy and cyclostationary detection [10], 4) *geo-location*, i.e. the locations of the CRS nodes and 5) *database usage,* e.g. database access to obtain information on available frequencies at the current location of the CRS node [11].

ITU-R concluded in the report that CRS technology may in the future be used as one method to address issues of ever-increasing demand for frequency-spectrum and shortage of available frequency-spectrum, by adding a level of flexibility and improving the efficiency of spectrum use. The report also discusses potential benefits of CRS technology;
1) improving the efficiency of spectrum use by facilitating new coexistence possibilities such that land mobile system may be able to use unused frequency bands in a particular place at a particular time in an opportunistic manner,
2) additional flexibility, such as improved flexibility of spectrum management, increased operational flexibility over the lifetime of fielded equipment and improved robustness or resiliency to failure,
3) self-correction and fault tolerance by taking multiple corrective strategies using a CRS or by taking an approach to learn patterns of failures and responses by using a CRS,
4) a unique opportunity of deploying new public protection and disaster relief (PPDR) communication systems in disaster stricken areas or in emergency situations.

On the other hand, as discussed in Sect. 3.1, there still remain concerns on the introduction of CRS technology to the practical field. ITU-R also identified technical challenges to be overcome, for example;

- spectrum sensing techniques in relation to the reliability,

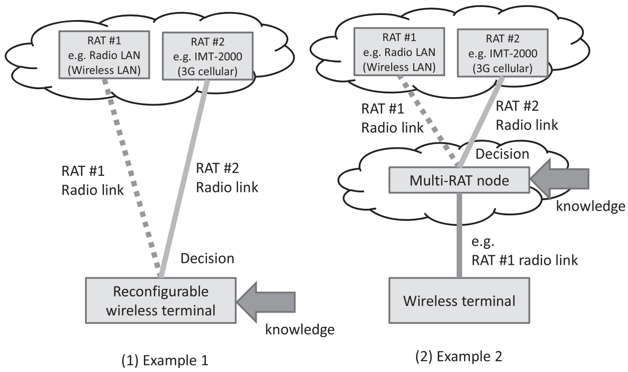

Fig. 4 Scenario 1 — terminal-oriented heterogeneous scenario.

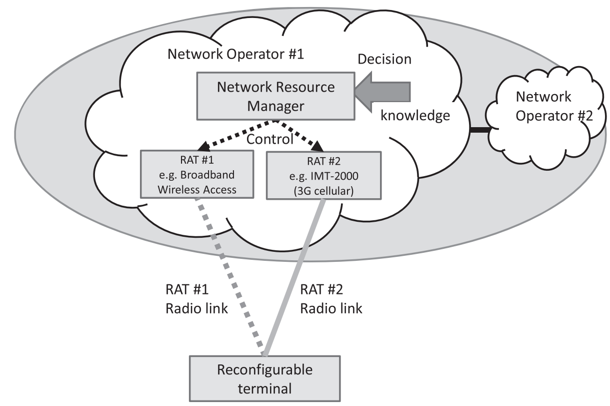

Fig. 5 Scenario 2 — network-oriented heterogeneous scenario.

accuracy and complexity of the different methods [10], [12], [13],

- the "hidden node" problem needs to be managed in order to guarantee the sensing reliability,
- 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, such as tuneable frequency usage, requiring high performance tuneable filters.

Research and development to work on the above challenges are encouraged.

It is useful to identify usage scenarios of CRS technology when considering regulatory impact of a CRS on current regulatory regime. ITU-R identified possible deployment scenarios for a CRS;

(1) Use of CRS technology to guide reconfiguration of connections between terminals and multiple radio systems

This is a terminal-oriented heterogeneous network scenario, in which multiple radio systems employing different radio access technologies (RATs) are deployed on different frequencies to provide wireless access. Two possible examples are identified; (i) Example 1: wireless terminals are reconfigurable and can adjust their operational parameters and protocols to use different RATs, according to their own decision by using the knowledge either obtained by themselves or provided by radio systems (e.g. using CPC),

(ii) Example 2: additional multi-RAT nodes (for example mobile routers) provide a connection to wireless terminals as a bridge between the wireless terminals and the multiple radio systems. These wireless terminals cannot reconfigure their operational parameters and protocols to use different RATs. Those examples are depicted in Fig. 4.

(2) Use of CRS technology by an operator of a radio communication system to improve the management of its assigned spectrum resource

This is a network-oriented heterogeneous network scenario, in which a network operator managing two or more RATs could use CRS technology to dynamically and jointly manage the resources of the deployed multiple RATs, in order to adapt the network to the dynamic behavior of the traffic and to globally maximize the capacity. The example of the scenario is shown in Fig. 5.

(3) Use of CRS technology as an enabler of cooperative spectrum access

In this scenario, information on spectrum use is exchanged among the systems in order to avoid mutual interference, as shown in Fig. 6. First example is a spectrum sharing among operators based on information among systems/networks on the usage of their respective assigned spectrum. Second example is a spectrum sharing between public land mobile network deployed and managed by the operators and private network that in principle are deployed in an arbitrary manner by the end users. In this scenario, interference problem between public land mobile networks and private networks, as well as, between multiple private networks due to the usage of the same spectrum bands may occur.

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

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, as shown in Fig. 7. The selection of the spectrum to be eventually accessed is made on a real

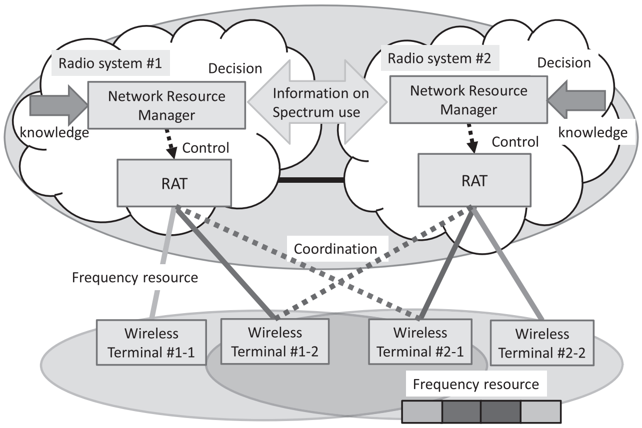

Fig. 6 Scenario 3 — cooperative spectrum access scenario.

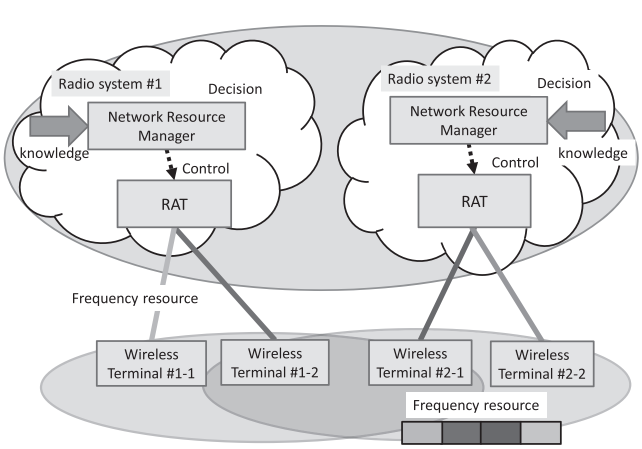

Fig. 7 Scenario 4 — opportunistic spectrum access scenario.

time basis following a radio environment analysis.

Examples are the use of Dynamic Frequency Selection (DFS) as sensing method by Radio LAN (RLAN) in the 5 GHz spectrum band [13] and the use of the unused portions of the UHF broadcast band (i.e. TV white spaces) [6]. In the discussion of example of TV white space, the terminology of TV white space was defined within ITU-R as;

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.

It should be noted that the above definition is for TV white space but not for white space in general. The definition of general "white space" has not yet been determined in ITU-R.

The first two scenarios (1) and (2) are heterogeneous network scenarios which are less challenging for their deployment since each radio access network can be managed separately without extra consideration of interference to other radio systems. The scenario (3) is a cooperative spectrum access in which frequency resource is coordinated by using spectrum-sharing information. The scenario (4) is an opportunistic spectrum access which further requires technical maturity to ensure the protection from harmful interference to other radio systems. These scenarios may impact on the sharing condition with other radio systems. In any scenario, ITU-R studies concluded that there is no need to change the current international regulatory framework and that any issues arising from the introduction of a CRS can be solved by developing or revising ITU-R Recommendations and/or Reports, e.g. on spectrum sharing studies.

3.2.2 Cognitive Radio Systems Specific for IMT Systems

ITU-R Working Party 5D (WP5D) deals IMT (International Mobile Telecommunications) system, which encompasses both 3G cellular systems and systems beyond 3G. WP5D developed a report on cognitive radio systems specific for IMT systems [15]. The report focuses on intra-operator scenarios since the scenarios seem to take the full benefit of some CRS capabilities in a harmonized, global and regulated IMT spectrum environment. This means that an improvement in the use of spectrum is obtained by accessing spectrum resources from one IMT system to other IMT system within the same single operator. The multiple operator case has not yet discussed in the report. Based on this view, the report identified the following CRS usage scenarios for IMT systems;

(1) update of a network for optimized radio resource usage within a single operator, in case of temporal and geographical variation of the traffic as well as the variation among IMT RATs, if multiple RATs are deployed by the operator,
(2) upgrade of an existing RAT or a network (for example IMT-2000 system) with a new RAT (for example IMT-Advanced system), in this scenario the phased resource reallocations within the same frequency band is possible,
(3) in-band coverage or capacity improvement by relay, in the scenario CRSs may identify the available resources to configure and optimize the relay scheme,
(4) self-configuration and self-optimization of femtocells,
(5) multi-mode coexistence and simultaneous transmission, in which harmful interference among the different RATs can be avoided by CRSs.

The report also identifies potential benefits of using CRS in IMT systems.

(1) overall spectrum efficiency and capacity improvements,
(2) radio resources utilization flexibility, to optimize parameters, such as bandwidth, operation frequency and transmission power,
(3) interference mitigation by intelligent selection of the frequency.

4. Conclusions

This paper has given an overview of ITU-R standardization activities on cognitive radio systems. First, ITU-R and WRC were introduced as background information. Then, WRC-12 agenda item 1.19 was explained which trigged ITU-R's regulatory study on CRS. As the result of the study, ITU-R concluded that CRS is not a radio communication service but a system employing technology that can be implemented in a wide range of applications in the land mobile service, and therefore there is no need to revise ITU-R RR with regard to the introduction of the CRS. WRC-12 made a final decision in align with the conclusion above. The paper also summarizes the concerns expressed by interested ITU-R Study Groups and Working Parties in the introduction of a CRS. Main concern was interference from a system employing CRS technologies, particularly to passive services. With regard to the technical and operational study in ITU-R, definition for CRS was agreed and fundamental concept of CRS was also developed. Furthermore, four deployment scenarios were identified for a CRS which are useful to discuss regulatory impact of CRS on current regulatory regime. The paper also introduced the results of ITU-R study on CRS specific for IMT cellular system, which only dealt a single-operator case.

ITU-R expects that CRS could improve the efficiency of the spectrum use although ITU-R sees that CRS technology is still at an early stage of research and development towards its full-fledged concept. Further research and development are continuously encouraged under more practical assumptions and reasonable evaluation conditions.

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