

Standardization and Research in Cognitive and Dynamic Spectrum Access Networks: IEEE SCC41 Efforts and Other Activities

Fabrizio Granelli, Przemysław Pawełczak, R. Venkatesha Prasad, K.P. Subbalakshmi, Rajarathnam Chandramouli, James A. Hoffmeyer, and H. Stephen Berger

Abstract

Spectrum crowding, spectrum management, quality of service and user support are the topics of vigorous research in the Cognitive and Dynamic Spectrum Access network communities. As research matures, standardization provides a bridge between research results, implementation and widespread deployment of such networks. This article reports recent developments within the IEEE Standardization Coordinating Committee 41 (IEEE SCC41) “Dynamic Spectrum Access Networks.” It outlines possible future standardization topics for IEEE SCC41, in the framework of other related standardization activities, and discusses open research issues that present future challenges for the standardization community.

The authors are members of IEEE SCC41, however the views presented herein are those of the authors and do not represent the views of the IEEE SCC41 or its projects.

Fabrizio Granelli is with the Department of Information Engineering and Computer Science, University of Trento, Via Sommarive 14, I-38100 Povo, Trento, Italy (email: granelli@disi.unitn.it).

Przemysław Pawełczak is with the Department of Electrical Engineering, University of California, Los Angeles, 56-125B Engineering IV Building, Los Angeles, CA 90095-1594, USA (email: przemek@ee.ucla.edu).

R. Venkatesha Prasad is with the Department of Electrical Engineering, Mathematics and Computer Science, Delft University of Technology, Mekelweg 4, 2600 GA Delft, The Netherlands (email: r.r.venkateshaprasad@tudelft.nl).

K.P. Subbalakshmi and Rajarathnam Chandramouli are with the Department of Electrical and Computer Engineering, Stevens Institute of Technology, Hoboken, NJ 07030 (email: {ksubbala, mouli}@stevens.edu).

James Hoffmeyer is the president of Western Telecom Consultants, Inc., 1168 Fletcher Drive, Eire, CO 80561 (email: jhoffmeyer@ieee.org).

H. Stephen Berger is the president of the International Association of Radio and Telecommunications Engineers (iNARTE) and of TEM Consulting, LP, 140 River Road, Georgetown, TX 78628 (email: stephen.berger@ieee.org).

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I. INTRODUCTION

The increase in computational abilities of current electronic devices and recent developments in computer science and artificial intelligence have permitted researchers to start thinking about introducing cognitive functionalities in wireless networks and devices. These functionalities allow wireless systems to become more flexible. They also enable appropriate actions by adapting the internal parameters, after inferring from the environment, to best fulfill the needs of the user. It is expected that these cognitive-enabled wireless systems will be the dominating force in combating observed scarcity of the radio spectrum. Thus the idea of Cognitive Radio (CR), as it is called in the literature, has attracted considerable attention. Since the introduction of this concept in 1999 by Mitola [1] many research results have been reported on this topic.

Growing interest in CR was demonstrated by start in 2005 of the IEEE Communications Society Technical Committee on Cognitive Networks [2]. Moreover, due to the importance of CR, IEEE initiated in 2004 a set of standardization projects related to CR called IEEE P1900, which evolved in 2006 into IEEE Standards Coordinating Committee 41 (IEEE SCC41) “Dynamic Spectrum Access Networks” [3]. The activities of IEEE SCC41 aim at facilitating the development of research ideas into standards to expedite the use of research results for public use. Now, the IEEE SCC41 has become the premier forum for standardizing concepts related to CR [4].

CR standardization as well as research has dramatically evolved since recent discussions on the topic [4], [5]. For example, the utility of CR has been recognized by ETSI and 3GPP as an important enabler for future wireless services. Therefore this article reviews recent achievements of IEEE SCC41 as well as unexplored issues in the field of CR standardization. It also discusses non-IEEE SCC41 CR standardization activities, like those of ITU-R, ETSI, OMG, SDR Forum and 3GPP.

The rest of the article is structured as follows. Detailed description of IEEE SCC41 is provided in Section II, while Section III provides an overview of open issues in research and standardization of CRs, that could be included in the future activities of IEEE SCC41. Section IV provides description of

other standardization activities related to IEEE SCC41. Finally, Section V outlines some ideas to tighten interaction between research and the standardization communities.

II. IEEE SCC41: GOALS, STRUCTURE AND ROADMAP

This section provides an overview of the goals, structure and roadmap of IEEE SCC41. Based on a summary of IEEE SCC41 structure from [4], [5], additional and updated information on recent developments is given.

A. Goals of the IEEE SCC41

The objective of IEEE SCC41 is to develop standards supporting new technologies for the next generation radio and advanced spectrum management. The IEEE Communications Society and IEEE Electromagnetic Society began sponsoring, in 2004, initial projects related to CR in the IEEE 1900 series. The IEEE Standards Association directed in 2006 the reorganization of this effort as Standards Coordinating Committee 41 with Dynamic Spectrum Access (DSA) networks as the assigned scope, where “the focus is on improved use of spectrum.” In other words, IEEE SCC41 deals with an area of technological convergence, wherein radio engineering, wireless networking, computer science, software engineering, network management and other disciplines contribute to the success of CR deployment.

Active dialog between different standard bodies is crucial for IEEE SCC41. SCC41 initiates and maintains interaction with relevant IEEE and external standards committees. For example, through the IEEE sector membership in the International Telecommunications Union Radiocommunications (ITU-R) section, IEEE SCC41 has provided inputs from its work to the ITU-R. IEEE SCC41 also interacts with regulatory bodies such as US Federal Communications Commission (FCC), the UK Office of Communications, and other national regulatory entities.

IEEE SCC41 believes that CR standardization can be considered as an interacting process of business case, technology, and policy, as depicted in Fig. 1. Although research is typically thought of as a technological component only, business cases and policy research must be taken into account, especially in CR standardization. A brief account of these aspects is discussed below.

- *Business Cases*: The current forecast is that the communication world, especially in the access loop, will be completely wireless. This implies a growing need for spectrum resources for many devices, which are anticipated to flood the market. As a consequence, the development of efficient techniques to optimize spectrum usage and access is required. Thus, the user requirements drive new business cases, which in turn drive the need for more spectrum. New radio technologies, like Ultra Wide

Band and methodologies such as Policy Radio, Opportunistic Spectrum Access, CR and networks which utilize these radio technologies are opening up new business opportunities. The extra efforts in the direction of reusing the spectrum as well as the standardization of these aspects mainly depend on the business opportunities for various players, i.e., manufacturers and service providers.

- *Technologies*: Businesses that generate new requirements is responsible for promoting technology developmental activities. Thus, industry and academia are driven towards finding new methods, in this case, for more efficient spectrum use methods.
- *Policies*: The technology alone cannot support the requirements generated by new business cases. The technology can prove what can be done, but it does not account for the development of the business and reaching out to the end users. Thus, the above two steps can yield success only if supported by new initiatives in regulatory procedure. In the CR scenario, policies are enforced by national regulators as well as international committees, e.g. ITU-R.

Given the goals of IEEE SCC41, we will now describe in detail each work group (WG) in the next section.

B. IEEE SCC41 Structure

A schematic representation of all IEEE SCC41 WGs is represented in Fig. 2 (top), while the timeline of IEEE SCC41 (and other important milestones in CR standardization described in later sections) is given in Fig. 2 (bottom). IEEE SCC41 is currently structured into five active WGs. Each WG is responsible for drafting a standard for a specific topic described below.

1) *IEEE 1900.1: Definitions and Concepts for Dynamic Spectrum Access: Terminology Relating to Emerging Wireless Networks, System Functionality, and Spectrum Management*: IEEE 1900.1 standard, approved on 26 September 2008 by IEEE Standards Association as an operative standard, acts as a glue to other IEEE SCC41 WGs by providing common definitions of terms and concepts. This common vocabulary is critical to the CR community, assuring a common understanding of the technical terms. This was necessitated since various research groups and industries were using the terms in this arena merely from their view point. Therefore it is necessary to have a common understanding to assure accurate and precise communication. The IEEE 1900.1 standard provides normative definitions supplemented with informative text. This informative material is necessary because of the complexity and interrelation of the terms for which normative definitions are provided. It further provides explanations to germinate a coherent view of the various efforts that are taking place in the broad area of CR.

2) *IEEE 1900.2: Recommended Practice for the Analysis of In-Band and Adjacent Band Interference and Coexistence Between Radio Systems*: IEEE 1900.2 standard, approved on 29 July 2008 by IEEE Standards Association, documents all aspects of a framework for analyzing the interference and coexistence between different wireless systems. The cost-gain tradeoffs of using a particular system, the harmful interference (and its thresholds) and their impacts are all considered in the analysis, since new wireless technologies, while attempting to improve spectral efficiency by being flexible, collaborative, and adaptive, can cause interference and co-existence issues. Therefore this WG established a common standard platform on which the disputing parties can present their cases and resolve them amicably.

3) *IEEE 1900.4: Architectural Building Blocks Enabling Network-device Distributed Decision Making for Optimized Radio Resource Usage in Heterogeneous Wireless Access Network*: IEEE 1900.4 standard addresses DSA and network operational issues in heterogeneous wireless networks. With the availability of multiple wireless systems on terminals, the network or the terminals need to decide in a distributed manner which system to use. Thus, the distributed decision making in such heterogeneous networks is an important characteristic. The network architecture which enables reconfigurability of terminals for such a system providing the QoS and increasing spectrum utilization is addressed in the standard. The functionalities and the interaction between the network and the devices are also addressed. This WG has a strong participation from the EU funded End-to-End Reconfigurability project, as well as from industry. IEEE 1900.4 WG was approved by the IEEE Standards Association on 27 February 2009. More detailed information on this WG can be found in [6].

From 19 March 2009 IEEE 1900.4 WG has started work on two new projects:

a) *1900.4a: Architectural Building Blocks Enabling Network-Device Distributed Decision Making for Optimized Radio Resource Usage in Heterogeneous Wireless Access Networks – Amendment: Architecture and Interfaces for Dynamic Spectrum Access Networks in White Space Frequency Bands*: IEEE 1900.4a is aiming at the definition of architecture and interfaces for efficient utilization of “white space,” i.e., the unused wireless spectrum. Since the available white space differs from country to country, and is essentially an ever-changing context, this WG activity is focused on creating a common system for white space devices to manage whatever available white space they have.

b) *1900.4.1: Interfaces and Protocols Enabling Distributed Decision Making for Optimized Radio Resource Usage in Heterogeneous Wireless Networks*: This project provides detailed description of interfaces and service access points defined in the IEEE 1900.4 standard, enabling distributed decision making in heterogeneous wireless networks and obtaining context information for this decision making process. This standard facilitates innovative, cost-effective, and multi-vendor production of network and

terminal side components of IEEE 1900.4 system and accelerates commercialization of this system to improve capacity and quality of service in heterogeneous wireless networks.

4) *IEEE 1900.5: Policy Language and Policy Architectures for Managing Cognitive Radio for Dynamic Spectrum Access Applications*: IEEE 1900.5, started in August 2008, aims at defining a policy language (or a set of policy languages or dialects) to specify inter-operable, vendor-independent control and behavior of CR functionality for DSA resources and services. In other words, the purpose of the WG is to define a set of policy languages, and their relation to policy architectures, for managing the features of CR for DSA applications. The initial work is concentrated on standardizing the features necessary for a policy language to be bounded to one or more policy architectures to specify and orchestrate the functionality and behavior of CR features for DSA applications.

5) *IEEE 1900.6: Spectrum Sensing Interfaces and Data Structures for Dynamic Spectrum Access and other Advanced Radio Communication Systems*: IEEE 1900.6, was also started in August 2008. The intended standard will define the information exchange between spectrum sensors and their clients in radio communication systems. The logical interface and supporting data structures used for information exchange will be defined abstractly without constraining the sensing technology, client design, or data link between sensors and clients.

It is important to note that IEEE P1900.3 WG (*Dependability and Evaluation of Regulatory Compliance for Radio Systems with Dynamic Spectrum Access*) due to lack of volunteers was dismantled in 2008. The primary focus of this WG was to provide a set of tests and evaluation methods to be used in regulatory compliance testing of CR devices.

C. Roadmap of IEEE SCC41

Notwithstanding the work in all active WGs, IEEE SCC41 has taken an initiative to invite more projects and potentially setup new Study Groups (SGs) or WGs. SCC41 has developed a process for the evaluation of new project proposals. A new project proposal may first be given SG status to further evaluate the viability of the project and interest by the community. However, if it is clear in advance that there are a significant number of parties interested in a standardization topic, a Project Approval Request will be submitted to the IEEE Standard Association Standards Board for approval as a WG without going through the intermediate states, such as SG. Thus, IEEE SCC41 is actively working as an incubator and an umbrella for supporting, facilitating and encouraging the efforts for standardization of the multi-faceted issues of cognitive communications.

III. OPEN ISSUES IN IEEE SCC41 STANDARDIZATION

The scientific community, inspired mainly by the work on CR [1] and on Cognitive Networks (CNs) [7], focused on the analysis of the specific issues and the identification of possible architectures to support CRs as a way to improve spectrum utilization on the one hand and, CNs as a suitable framework for network self-configuration and QoS provisioning, on the other. In the standardization framework, the work of IEEE SCC41 is relatively new with many challenges to be addressed, some of those derived from problems outlined in the literature. We will outline some of the potential and relevant issues to be addressed by IEEE SCC41.

A. Regulation and Testing

Regulatory bodies must assure that devices in the CR field conform to contemporary and future requirements for radio equipment. To achieve this goal, a conformity assessment apparatus must be developed using many components, such as equipment certification, quality control and field monitoring. Providing regulators with the standards they require to fulfill their mandate is an area for many future projects. Regulation documents would describe methods to measure the interference caused by CR and CNs and quantify the “intelligence” of such devices. With this background it is important to restore the work of IEEE P1900.3, which had some of these goals in mind.

B. System Design and Networking

There are certainly many aspects of CN systems that need standardization. While Wireless Regional Access Networks are getting covered by CR standards, for instance IEEE 802.22, other wireless network types are not standardized with respect to CR. One important aspect of network design is Medium Access Control (MAC). In the case of wireless ad hoc and sensor networks, distributed MAC protocols operating in opportunistic spectrum access manner (on licensed and unlicensed channels), are not yet covered by any standard. Contemporary intelligent spectrum management standards, such as IEEE 802.11k, cover only the unlicensed bands. Therefore there is a need for a generalized CR-MAC, which will take into account many of the specificities of CR. It is envisaged that many future versions of MAC will inherit from this generalized CR-MAC.

Another issue is cross-layer design, meant as an inter-layer interaction of CN entities. While this aspect is included in the concept of CNs as a means to support user and applications requirements, no relevant and comprehensive analysis is available to address the performance and behavior of applications and networks based on CR and CN technology [8]. Unique signaling architectures are needed in order to

enable internal or network-wide exchange of information and commands between cognitive devices or among distributed devices constituting a single cognitive entity. While the debate on cross-layering has already gained maturity, even with conflicting ideas [9], it is worthwhile to address signaling architecture as a relevant point to support cross-layer or general optimization solutions.

C. Security

Although existing wireless security standards can be used in CR networks for certain aspects, e.g. encryption, there are several unique challenges that arise merely due to the opportunistic nature of spectrum access [10], [11]. For example, in order to accurately sense white spaces, as well as to securely transmit this decision to all nodes in the secondary network, it is not only necessary to design stand-alone optimal sensing techniques, but also authenticated encryption enabled protocols that will allow a reliable, joint, and speedy decision for the entire network. Hence, a more holistic approach is needed while designing the several components of the CR network. A good design will result in accurate and secure primary user (PU) detection [10], resilience to non-jamming Denial of Service (DoS) attacks on the secondary user [11] (SU), efficient and fair spectrum sharing, accurate authorization, and computational efficiency.

In order to understand the components needed to design a secure CR network, it is necessary to understand the threats that a CR network could face. The problem of spectrum opportunity detection is intimately connected with the problem of detecting PU activity in any given band. If this key functionality is not accurately implemented one of the following undesirable situations could occur.

- *DoS Attacks on the Secondary Network:* If a set of malicious agents can impact the decision on PU activity, so that the non-malicious agents repeatedly come to the conclusion that a primary is present when indeed it is not, then this could result in several missed opportunities for the non-malicious SU network. Further, because the non-malicious SU will resume the search for an available band until it finds an empty one, this could potentially lead to quick power depletion for the SU. The problem gets even more complicated when the SU node is a participant in an established secondary communication. This is because the node will have to tear down its existing connections and set-up an agreement with communicating nodes for a rendezvous channel. If a dedicated channel is not available for rendezvous, each node will have to asynchronously search for a common available channel to resume communication. If the DoS attack is coordinated, the algorithm for the rendezvous may not converge quickly, if it converges at all. Hence emerging standards need to consider this important problem in the specification of the sensing protocol, the decision protocol (especially when

centralized decisions are made) and rendezvous protocol.

- *DoS Attacks on the Primary Network*: This problem arises when the malicious entities refuse to leave the band when a PU arrives, which potentially affects decision of other SUs (with no malicious intent) by propagating false notions regarding the return of PU. In light of the fact that the US FCC has recently discontinued the use of interference temperature (IT) as a metric for measuring the disruption caused by any node, IT based solutions to automatically exclude errant nodes may not be possible. Besides, it would be ideal to isolate the malicious nodes rather than the nodes that were inadvertently fooled. Although this is a harder goal, this may be potentially important in order to prevent an accidental partial DoS on the SU network when defending against DoS on the PU network.

To summarize, it is important to define metrics that can be used to capture the level of security in a DSA and CR network. In order to achieve a high level of security, a variety of solutions would have to be co-adopted in the upcoming standards, including those that are used in cryptographic security and authentication, game theory, fault tolerance, statistical signal processing etc.

IV. COGNITIVE RADIO RELATED STANDARDS

Given the description of IEEE SCC41 it is also important to look at other standardization endeavors, inside and outside of IEEE. For a similar discussion we refer to [5].

A. IEEE 802.22

To make universal broadband access a reality, to allow Internet service industry to grow, and to make the consumer Internet access competitive, the TV white spaces were opened for unlicensed use in USA by the FCC in 2008. Luckily, already in 2005 IEEE 802.22 took the initiative to define a standard to use TV white spaces [12].

IEEE 802.22 is thought of as an alternative technology to IEEE 802.11, operating in a spectrum range that allows better and further propagation (54-863 MHz). Physical and MAC layer of IEEE 802.22 is similar to IEEE 802.16 with the amendments related to the identification of the PUs and defining the power levels so as to not to interfere with the adjacent bands. The two important entities defined in the standard are the Base Station (BS) and Customer Premises Equipment (CPE). BS controls all the CPEs decisions as to when to send data and the channels to use. CPEs sense the spectrum in its vicinity, helping in distributed detection of PU activity. At the time of writing this paper IEEE 802.22 was still in the standard drafting phase. Document reached version 2.0 in May 2009.

B. Standards Related to IEEE 802.16

IEEE 802.16 group has its own set of standards that support CR-like functionalities. IEEE 802.16.2-2004, which superseded IEEE 802.16.2-2001 in March 2003, describes engineering practices to mitigate interference in fixed Broadband Wireless Access (BWA) systems. This document explained methods of efficient coexistence of multiple BWA systems. IEEE 802.16a-2003, as an amendment to IEEE 802.16-2001 and completed in March 2003, described the operation of Wireless MAN interface of BWA networks in license-exempt bands. It also discussed interference analysis and coexistence issues for BWA networks in these bands. Finally, improved coexistence of IEEE 802.16-based networks working in the unlicensed bands is covered by IEEE 802.16h WG. At the time of writing this article IEEE 802.16h is in the IEEE Standards Association sponsor ballot stage.

C. Standards Related to IEEE 802.15

Wireless Personal Area networks, covered by the work of IEEE 802.15 group, work in the license-exempt bands and also has its own set of standards related to coexistence. These include IEEE 802.15.4-2003 (completed in May 2003), which describes dynamic channel selection mechanisms, and IEEE 802.15.2-2003 (completed in June 2003), which describes general coexistence guidelines.

D. Standards Related to IEEE 802.11

Coexistence mechanisms are also included in IEEE 802.11 standards: IEEE 802.11-2007 and IEEE 802.11y-2008. IEEE 802.11-2007, published in July 2007, describes dynamic frequency selection and transmit power control for coexistence with satellite and radar systems operating in 5 GHz band, first described in IEEE 802.11h. IEEE 802.11y-2008, approved in September 2008, is an extension of IEEE 802.11 to 3650-3700 MHz frequency range, which is shared with satellite earth stations.

E. IEEE 802.19

This standard defines general coexistence metrics for all IEEE 802 networks working in the unlicensed bands. Although focusing on IEEE 802 networks, the guidelines of the standard can be applicable to other unlicensed wireless systems. Currently, IEEE 802.19 technical advisory group is evaluating coexistence between IEEE 802.11y and IEEE 802.16h.

F. ITU-R Activities Related to CR

Standardization bodies outside of IEEE are also working on their own set of standards related to CR, and ITU-R is particularly active. In the CR implementation domain, ITU-R published in 2007 ITU-R Report M.2117 entitled *Software defined radio in the land mobile, amateur and amateur satellite services*. In the ITU-R Resolution 805 (Agenda for 2011 World Radiocommunication Conference) in Agenda Item 1.19 ITU-R decided “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 (*Regulatory measures and their relevance to enable the introduction of software-defined radio and cognitive radio systems*).” In a similar Resolution 951 (*Enhancing the international spectrum regulatory framework*), ITU-R concluded “that evolving and emerging radiocommunication technologies may enable sharing possibilities and may lead to more frequency-agile and interference tolerant equipment and consequently to more flexible use of spectrum.” To address WRC-11 Agenda Item 1.19 Study Group 1 (*Spectrum Management*) has been assigned to be the lead organizational entity within ITU-R.

ITU-R Study Group 5 (*Mobile, Radio determination, Amateur and Related Satellite Services*) Working Party 5A (*Land mobile service excluding IMT-2000; amateur and amateur satellite services*) will continue its work on the development of an ITU-R Report entitled *Cognitive Radio Systems in the Land Mobile Service*. This work is in response to two Questions on SDR and CRS assigned to ITU-R Working Party 5A: ITU-R 230-2/5 (*Software Defined Radios*) and ITU-R 241-1/5 (*Cognitive Radio Systems in the Mobile Service*). Note that in ITU-R terms a Question “is a statement of a technical, operational or procedural problem, generally seeking a Recommendation, Handbook, or Report”.

G. SDR Forum Activities

SDR Forum is also involved in several activities related to CRs, CNs and DSA. Recent operation plan from January 2009 described the following activities:

- The CR WG is initiating preparation of a literature survey to identify and present quantifiable metrics that objectively measure the benefits of CR technology. Initial work on this report is expected to conclude in 2009.
- The group “Test Guidelines and Requirements for Secondary Spectrum Access of Unused TV Spectrum” will aim at use cases and test requirements for the use of CR techniques to allow unlicensed secondary spectrum access for unused TV bands.

- *Test and Measurement of Unique Features for Software-Defined/Cognitive Radios* report is being prepared by the Test and Measurement Task Group to identify the unique test challenges created by systems with SDR/CR features and propose solutions in such a framework.
- The CR Market Study will represent a market study focused on CR and white space communications, to be delivered during 2010.

Apart from this, in the course of 2009 and 2010, SDR Forum will aim at projects related to different topics such as certification of CR Technologies, CR Architecture Recommendations, Design Processes and Tools and Hardware Abstraction Layer for CR.

H. ETSI Standards Related to CR

In February 2008, European Telecommunications Standards Institute (ETSI) started a new technical committee on Reconfigurable Radio Systems (RRS), with liaison with IEEE SCC41 and SDR Forum. RRS has four groups: WG1 (System Aspects), WG2 (Radio Equipment Architecture), WG3 (Functional Architecture for Cognitive Pilot Channel), and WG4 (Public Safety). WG1 issued two drafts related to technical recommendations: DTR/RRS-01002 “Cognitive Radio system concept” and DTR/RRS-01003 “Spectrum Aspects of Cognitive Radio and Software Defined Radio Systems.” WG2 issued three documents: one complete technical recommendation TR 102 680 “SDR Reference Architecture for Mobile Device”, and two draft recommendations DTR/RRS-02003 “Radio Base Station Software Defined Radio status, Implementations and Costs Aspects, Including Future Possibilities” and DTR/RRS-02004 “Multiradio Interface for Software Defined Radio Mobile Device Architecture and Services.” WG3 published two draft recommendations DTR/RRS-03004 “Functional Architecture” and DTR/RRS-03007 “Cognitive Pilot Channel Design.” Finally WG4 issued two draft recommendations: DTR/RRS-04005 “System Aspects for Public Safety” and DTR/RRS-04006 “User Requirements for Public Safety.”

I. Object Management Group Activities

The Object Management Group (OMG) is also involved in activities related to next generation radio systems, with the Software Radio Special Interest Group and the Software-Based Communication Domain Task Force. The mission of Software-Based Communication (SBC) Domain Task Force (DTF) is the development of specifications supporting the development, deployment, operation and maintenance of software technology targeted to software defined communication devices. The SBC DTF targets mainly issues related to the use of UML and model driven development technology for SDR, interoperability

and exchangeability of software-defined components, and in general attempts to broaden the scope to new related technologies, e.g. CR, Digital Intermediate Frequency, Spectrum Management, etc.

J. 3GPP Activities Around CR

The Third Generation Partnership Project (3GPP) is also interested in standardizing CR-like features in its future releases. In particular, 3GPP plans to enhance Long Term Evolution standard (radio interface of the UMTS) in Release 10 with CR functionalities. For example the idea of Cognitive Reference Signal is proposed through which each RAN can broadcast interference level, frequency bands, radio access technologies of other networks and other information which can help newly joined user equipment to chose the best RAN.

We summarize different aspects of standardization for CR in Table I.

V. CONCLUSIONS

IEEE SCC41 is providing a timely effort to standardize the frameworks of CRs and CNs. As we have shown, many additional issues require standardization and offer future work for IEEE SCC41. As given in Fig. 1, standardization should represent a melting pot of three aspects – technology, policy and business. To achieve this goal, all the above topics should converge within the working groups of any standardization effort.

To support proper balance amongst these three aspects, the IEEE Communications Society Technical Committees are collaborating with the IEEE Standards Association. This facilitates the interaction between the standards development process and the research community. In this framework, it will be useful to further increase involvement of researchers by building tighter links between IEEE Societies, their Technical Committees, and IEEE Standards Association activities. In this regard, a good starting point would be to identify a reference person to act as standards liaison in each committee, following what is currently being done by IEEE Communications Systems Integration and Modeling Committee. An alternative or complementary process for standardization committees would be to contact IEEE Technical Committees in order to solve specific problems within their research domain. Such action would activate a process, where contacted Technical Committees will activate specific WGs to produce a report for discussion with respective standardization WGs. A good example of discussion fora for the interaction of technology, policy and business in a CR framework are IEEE DySPAN and ICST CrownCom conferences. They represent the premier events dealing with DSA networks, regulations,

standardization, and implementation for CRs, interference and coexistence analysis, and also ongoing research and development efforts worldwide.

Summarizing, IEEE SCC41 represents a significant effort to foster standardization in the framework of next generation wireless systems by bringing together experts in technology, policy, and business cases. The results achieved demonstrate the capability of the working groups and project coordination as well as a relevant potential for further activities on the open issues identified in this article.

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Fabrizio Granelli Fabrizio Granelli received the “Laurea” (M.Sc.) degree in Electronic Engineering from the University of Genoa, Italy, in 1997, with a thesis on video coding, awarded with the TELECOM Italy prize, and the Ph.D. in Telecommunications from the same university, in 2001. Since 2000 he is Assistant Professor in Telecommunications and Co-Founder of the Dept. of Information Engineering and Computer Science, University of Trento (Italy) and coordinator of the Networking Laboratory. In August 2004, he was visiting professor at the State University of Campinas (Brasil). He is author or co-author of more than 90 papers published in international journals, books and conferences. Dr. Granelli is guest-editor of ACM Journal on Mobile Networks and Applications, special issues on “WLAN Optimization at the MAC and Network Levels”, “Ultra-Wide Band for Sensor Networks” and “Recent Advances in IEEE 802.11 WLANs: Protocols, Solutions and Future Directions”. Dr. Granelli is General Vice-Chair and Founder of WICON05, General Chair of CAMAD06, and General Co-Chair and Founder of MOBILIGHT09. He is TPC Co-Chair of IEEE GLOBECOM 2007-2009 Symposia on “Communications QoS, Reliability and Performance Modeling” and of IEEE CAMAD08. His main research activities are in the field of networking, with particular reference to network performance modeling, cross-layering, medium access control, wireless networks, cognitive radios and networks. He is Senior Member of IEEE, Chair of IEEE ComSoc Technical Committee on Communication Systems Integration and Modeling (CSIM) and Associate Editor of IEEE Communications Letters, IEEE Communications Surveys and Tutorials and International Journal on Communication Systems.

Przemysław Pawełczak Przemysław Pawełczak obtained his MSc degree in electronics and telecommunications engineering from Wrocław University of Technology, Poland in 2004 and PhD degree from Delft University of Technology, the Netherlands in 2009. Between 2004 and 2005 he was a staff member of Siemens Software Development Center, Wrocław, Poland. During fall 2007 he was a visiting scholar at Connectivity Lab of University of California, Berkeley. He is currently a postdoctoral researcher at Cognitive Reconfigurable Embedded Systems Laboratory of University of California, Los Angeles. Dr. Pawełczak is the originator and organizing committee member of IEEE CogNet workshops, collocated with IEEE ICC 2007, 2008, and 2009. He is also a voting member of IEEE SCC41 Standardization Committee.

R. Venkatesha Prasad Dr. Venkatesha Prasad received his bachelors degree in Electronics and Communication Engineering and M.Tech degree in Industrial Electronics from University of Mysore, India in 1991 and 1994. He received a Ph.D degree in 2003 from Indian Institute of Science, Bangalore India. During 1996 he was working as a consultant and project associate for ERNET Lab of ECE at Indian Institute of Science. While pursuing the Ph.D degree, from 1999 to 2003 he was also working as a consultant for CEDT, IISc, Bangalore for VoIP application developments as part of Nortel Networks sponsored project. In 2003 he was heading a team of engineers at the Esqube Communication Solutions Pvt. Ltd. Bangalore for the development of various real-time networking applications. Currently, he is a part time consultant to Esqube. From 2005 till date he is a senior researcher at Wireless and Mobile Communications group, Delft University of Technology working on the EU funded projects MAGNET/MAGNET Beyond and PNP-2008 and guiding graduate students. He is an active member of TCCN, IEEE SCC41, and reviewer of many Transactions and Journals. He is on the TPC of many conferences including ICC, GlobeCom, ACM MM, ACM SIGCHI, etc. He is the TPC co-chair of CogNet workshop in 2007, 2008 and 2009 and E2Nets (2010) at IEEE ICC. He is also running PerNets workshop from 2006 with IEEE CCNC. He is the Tutorial Co-Chair of CCNC 2009 and Demo Chair of IEEE CCNC 2010.

K.P. Subbalakshmi K.P. (Suba) Subbalakshmi is an Associate Professor in the Department of the Electrical and Computer Engineering at Stevens Institute of Technology. Her research interests are in cognitive radio, wireless and information security. Her work is funded by the US National Science Foundation, the US Intelligence Systems Support Office, US Army ARDEC, National Institute of Justice etc. She was an invited Panelist speaker at the IEEE ICC 2008, on Security Issues in Cognitive Radio Networks. She was a co-organizer of the Symposium on Selected Areas of Communications in IEEE ICC 2009. She is a Guest Editor of the EURASIP Journal on Applied Signal Processing, Special Issue on Dynamic Spectrum Access for Wireless Networking, 2009. She was the founding co-organizer of the First Workshop on Security Privacy and Authentication in Wireless Networks, IEEE WoWMoM, 2008. She was a Special Sessions Co-Chair for CROWNCOM 2007. She was a Co-Chair of the Network Security Symposium of the IEEE International Conference on Computer Communications and Networks in 2007 and 2008. She was a Co-Organizer of the Symposium on Network and Information Systems Security, 2006. She is the Chair of the Security Special Interest Group of the IEEE Multimedia Technical Committee. She is also the Co-Founder of inStream Media, LLC, a start-up company developing interactive video technologies. More information is available at <http://personal.stevens.edu/~ksubbala>

Rajarathnam Chandramouli R. Chandramouli (Mouli) is the Thomas Hatrick Chair Professor of Information Systems in the Department of Electrical and Computer Engineering at Stevens Institute of Technology. His research spans the areas of wireless networking and security, human factors in Internet security and forensics, and applied probability theory. Projects in these areas are supported by the National Science Foundation, U.S. Army, Office of the Naval Research, Air Force Research Lab, National Institute of Justice and other Department of Defense Agencies. He is the Founding Chair of the IEEE COMSOC Technical Committee on Cognitive Networks (TCCN), Keynote speaker at Wireless Communications and Signal Processing Conference 2009, Member of the IEEE COMSOC Standards Board, Associate Editor of the Advances in Multimedia Journal and Journal of Communications, and International Advisory Committee Member of WCSP 2009. He was on the Steering Committee of CROWNCOM, General Co-Chair of CROWNCOM (2007), IEEE GLOBECOM 2007 Wireless Communications Symposium Co-Chair, Technical Program Vice-Chair of IEEE CCNC 2007 and 2008, Co-Chair of the Workshop on Cognitive Networks and Communications held with IEEE ICCCN 2009, Multimedia Communications Symposium Co-Chair of CHINACOM 2008, and Associate Editor of IEEE Transactions on Circuits and Systems for Video Technology. Prof. Chandramouli's work on cognitive wireless networks has won an IEEE GLOBECOM 2008 Best Paper Award and a IEEE CCNC 2006 Best Student Paper Award. He is also a recipient of the NSF CAREER Award and IEEE Richard E. Merwin Scholarship. He also the Co-Founder of inStream Media, LLC, a start-up company developing interactive video technologies. More information is available at <http://www.ece.stevens-tech.edu/mouli>

James A. Hoffmeyer James A. Hoffmeyer is president of Western Telecom Consultants, Inc. and was previously employed by the National Telecommunications and Information Administration where he managed a group of up to 25 engineers and scientists. He has over 25 years experience in wireless telecommunication. His current areas of interest include cellular systems, software-defined radio, cognitive radio systems, radio regulation, and international telecommunications standards development. He has held numerous standards leadership positions as Chair of the predecessor of the SDR Forum, and as Chair of working groups in the International Telecommunication Union (ITU) and in the IEEE Standards Association. He has published over 40 technical papers and reports and has developed more than 45 input contributions to the ITU and IEEE. Mr. Hoffmeyer was awarded the Department of Commerce Silver Medal while working for the NTIA Institute for Telecommunication Sciences. Mr. Hoffmeyers involvement with the IEEE Standards Association includes serving on the IEEE SCC41 Management Board, IEEE Communications Society Standards Board, IEEE 1900.1 Chair and IEEE 1900.5 Vice Chair.

H. Steven Berger Mr. Berger is president of TEM Consulting, an engineering services and consulting firm dealing in regulatory compliance, wireless and EMC. He is the current co-chair of IEEE SCC41, Dynamic Spectrum Access Networks, and chair of the IEEE EMC Society Standards Development Committee. He is also President of International Association of Radio and Telecommunications Engineers. Before forming TEM Consulting Mr. Berger was a project manager at Siemens Information and Communication Mobile, in Austin, Tx., where he was responsible for standards and regulatory management. He has worked in EMC and RF Safety for 20 years. More recently he has been active in the area of Disability Access to telecommunications and information technology products. He has written numerous technical papers and holds several patents in the area of wireless, EMC and Access technology.

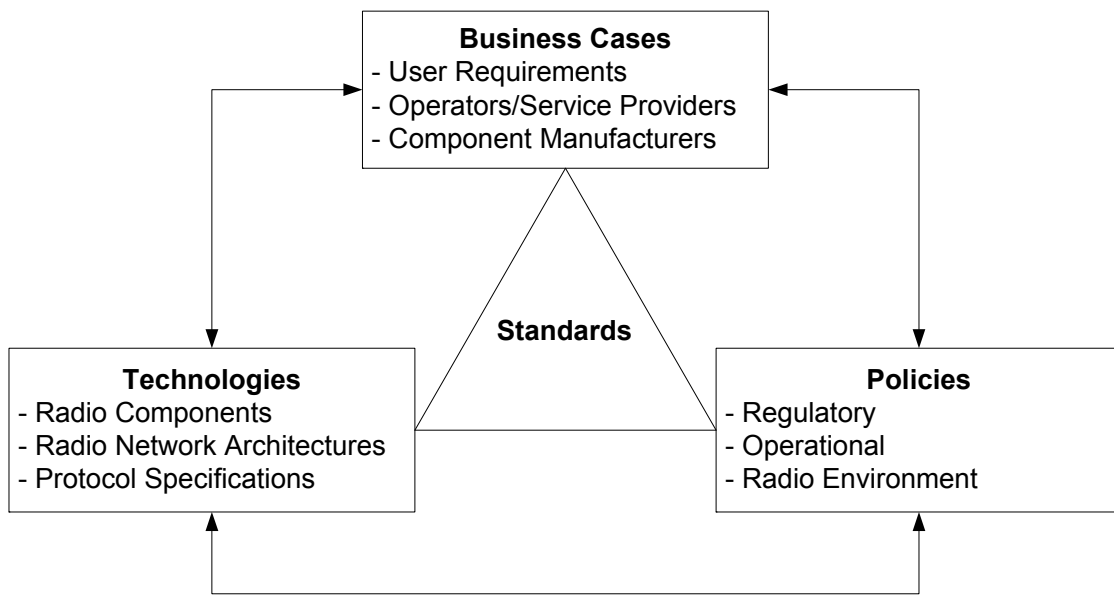


Fig. 1. Interaction between technology, policies and business case scenarios as the drivers of CR system standardization.

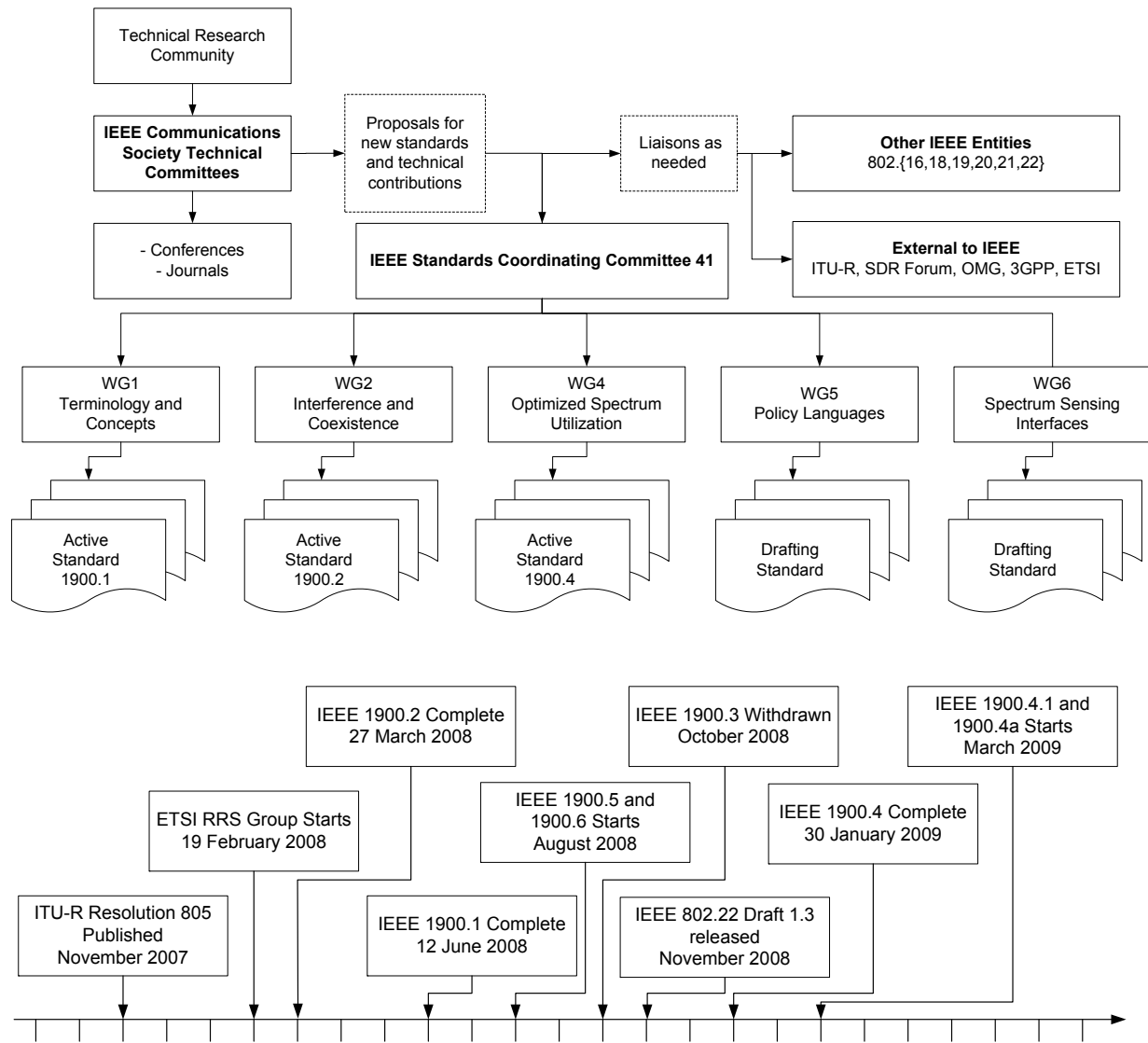


Fig. 2. CR standardization: (top) IEEE SCC41 organization structure and its relationship with other standardization entities (for comparison see [4, Fig. 2]); note the missing WG3 (see text). (bottom) Timeline of important standardization projects related to CR.

TABLE I
SUMMARY OF CR ACTIVITIES IN STANDARDIZATION AND OPEN ISSUES

Functionality	Covering Organization
Definitions	IEEE SCC41, ETSI, ITU-R
Coexistence	IEEE 802.19, IEEE SCC41
SDR	IEEE SCC41, SDR Forum, ITU-R, OMG
Radio Interfaces	IEEE 802.22, 3GPP
Heterogeneous Access	ETSI, IEEE SCC41
Spectrum Sensing	IEEE 802.22, IEEE SCC41
Testing	—
Networking (CR-MAC)	—
Security	—