

IEEE 1900.6: Spectrum Sensing Interfaces and Data Structures for Dynamic Spectrum Access and Other Advanced Radio Communication Systems Standard: Technical Aspects and Future Outlook

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ABSTRACT

Currently, the IEEE Standards Association is very active in the framework of cognitive radio with an aim to provide a bridge between research results, implementation, and widespread deployment of this new communication paradigm. This article reports recent developments within the IEEE Dynamic Spectrum Access Network Standards Committee¹ on dynamic spectrum access networks with particular consideration of IEEE 1900.6, “Spectrum Sensing Interfaces and Data Structures for Dynamic Spectrum Access and Other Advanced Radio Communication Systems.” It outlines the current structure of the IEEE 1900.6 standard and its relationship with other related standardization activities. We provide application scenarios and topology briefly, and discuss open research issues that raise future challenges to the standardization community.

INTRODUCTION

OVERVIEW

The convergence of information, multimedia, entertainment, and wireless communications has raised hopes of realizing the vision of ubiquitous and pervasive communication — anywhere, anytime, and with any device. To accommodate the explosion in the number of devices, obviously using wireless technologies and in turn frequency

spectrum, there must be a way to address the allocation and availability of wireless channels to all these devices. Dynamic spectrum sharing in *time* and *space* is one of the promising ways to address this. Thus, dynamic spectrum access (DSA) has become a key issue in the heterogeneous wireless communication ecosystem characterized by sharing of spectrum and coexistence with various other wireless enabled nodes. An intelligent wireless communication system that estimates or predicts spectrum availability and channel capacity, and adaptively reconfigures itself to maximize resource utilization while addressing interference mitigation, is highly desirable. Cognitive radio (CR) is an attempt in this direction. In fact, CR can help in two ways, by:

- Locating unused spectrum
- Intelligently selecting spectrum holes for allocating communication channels to harness spectrum opportunities

The latter aspect is highly relevant since a certain time after wide deployment of CR devices, spectrum holes may not be accessible as easily as they are currently. Thus, CR devices should manage and coexist with other CR and non-CR devices to efficiently use available spectrum opportunities. CR devices learn from observing the environment and may adaptively change the parameters of radio transmission to ensure highly reliable communication, including change of

¹ IEEE DySPAN-SC – IEEE Dynamic Spectrum Access Network Standards Committee was previously known as IEEE Standardization Coordinating Committee 41 (IEEE SCC41). This standardization effort is now placed directly under the IEEE Communications Society, and the transition is still going on.

modulation scheme, transmission power, carrier frequency, and channel coding [1]. Several research initiatives have been funded in Europe under Framework Programme 7 (FP7) [2–5] to assess the feasibility of the CR paradigm for new generation networks (NGNs), and a growing interest in CR has been demonstrated by the IEEE since the early stages of the research activity with the organization of several scientific conferences such as the first IEEE Dynamic Spectrum Access Networks (DySPAN) Symposium in 2005. Furthermore, in 2005 the IEEE initiated a set of standardization projects related to CR called IEEE 1900, which evolved in 2006 into IEEE Standards Coordinating Committee 41 (IEEE SCC41), Dynamic Spectrum Access Networks, which is now referred to as the IEEE DySPAN-SC [6]. The IEEE Communications and EMC Societies were sponsoring societies as they were for the IEEE 1900 effort [7]. The scope of the IEEE DySPAN-SC is to facilitate the development of research ideas into standards to expedite the use of research results for public use. We here briefly present the IEEE 1900 suite of standards to give readers a general overview of the framework of DSA standardization within the DySPAN-SC. More details can also be found in [8].

THE 1900.X SUITE OF STANDARDS

IEEE DySPAN-SC is structured into five working groups (WGs). Each WG is responsible for drafting a standard for a specific topic.

IEEE 1900.1: Definitions and Concepts for Dynamic Spectrum Access: Terminology Relating to Emerging Wireless Networks, System Functionality, and Spectrum Management: IEEE 1900.1 aims at providing common definitions of terms and concepts. On 22 March 2011 the 1900.1 WG started to work on project P1900.1a to amend the IEEE Std 1900.1-2008 with new terms and definitions.

IEEE 1900.2: Recommended Practice for the Analysis of In-Band and Adjacent Band Interference and Coexistence Between Radio Systems: IEEE 1900.2 describes all aspects of a framework for analyzing the interference and coexistence between different wireless systems.

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 defines the architecture and addresses DSA operational issues in heterogeneous wireless networks. On 19 March 2009 IEEE 1900.4 WG started to work on two new projects [9]:

- **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 spaces (i.e., the unused portions of wireless spectrum).

- **1900.4.1: Interfaces and Protocols Enabling Distributed Decision Making for Optimized Radio Resource Usage in Heterogeneous Wireless Networks:** This project provides detailed

descriptions of interfaces and service access points defined in the IEEE 1900.4 standard, enabling distributed decision making in heterogeneous wireless networks to obtain context information for this decision making process.

IEEE P1900.5: Policy Language Requirements and System Architectures for Dynamic Spectrum Access Systems: IEEE P1900.5 aims at defining requirements for a policy language (or a set of policy languages or dialects) to specify interoperable vendor-independent control and behavior of CR functionality for DSA resources and services.

IEEE 1900.6: Spectrum Sensing Interfaces and Data Structures for Dynamic Spectrum Access and other Advanced Radio Communication Systems: IEEE 1900.6 started in July 2008. It is the object of this article, and the structure and goals of IEEE 1900.6 are described in detail in the next section. On 20 June 2011 the 1900.6 WG started to work on project P1900.6a to amend IEEE 1900.6-2011 with procedures, protocols, and data archive enhanced interfaces, considering interfaces to existing spectrum sensing systems and geolocation databases.

IEEE 1900.7: Radio Interface for White Space Dynamic Spectrum Access Radio Systems Supporting Fixed and Mobile Operation: IEEE P1900.7 started in September 2011 aiming to develop a standard that defines the radio interface (medium access control [MAC] and physical [PHY] layers) for white space communication systems.

On July 7th, 2011 an ad hoc group on **Dynamic Spectrum Access in Vehicular Environments** was created within the IEEE DySPAN-SC. This group aims to identify the need for and direction of potential future standardization projects on dynamic spectrum access in highly mobile environments.

Hereafter, the important aspects of the IEEE 1900.6 standardization efforts are described. Furthermore, some discussion on other related standards is taken up in the remainder of the article.

IEEE 1900.6 APPLICATION SCENARIOS

Many emerging CR applications are created with particular focus on smart grid, public safety, cellular, and wireless medical networks, as given in [10]. Figure 1 summarizes many of the use cases where dynamic and opportunistic spectrum access is used. The scenarios in Fig. 1 are:

- A combat zone where an ad hoc network needs to be set up
- An emergency situation where firemen are working together to find and help survivors
- A policeman trying to reach the headquarters
- A simple ad hoc network in a home

In the above scenarios we see many sensors. These sensors are sometimes standalone or can form a small network of collaborating sensors gaining information about the available spectrum. This information is then used by various applications such as those listed above. Often,

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IEEE 1900.6 standardizes the information exchange between spectrum sensors and their clients in advanced radio communication systems in a technology-neutral way, which makes it possible to achieve independence from the underlying technology.

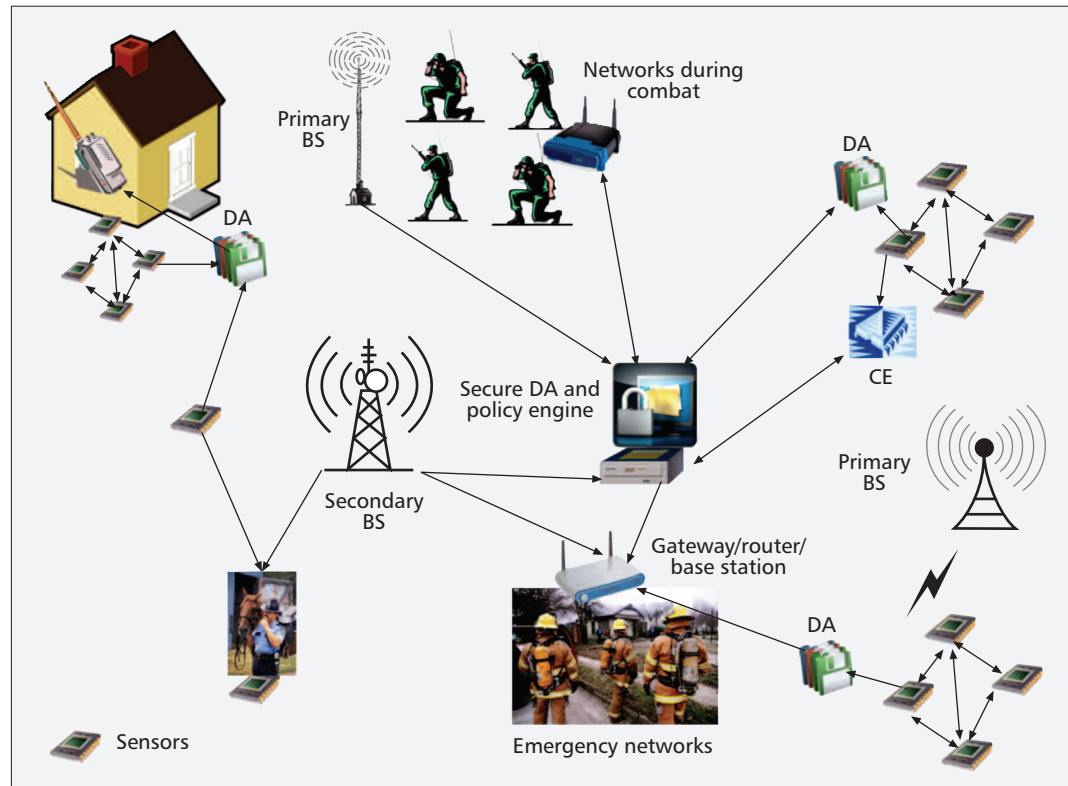


Figure 1. Application scenarios.

the sensors would indeed talk to a data archive (DA), which can be considered a database where sensed information about spectrum occupancy is stored and provided. A cognitive engine (CE) is an entity utilizing cognitive capabilities including awareness, reasoning, solution making, and optimization for adaptive radio control and implementation of spectrum access policies. Information exchange between sensors, DAs, and CEs is necessary to disseminate spectrum availability and reduce interference to incumbent spectrum users. Thus, we need an interface that sensors can utilize to talk to each other as well as to CEs or DAs. In distributed scenarios sensors, CEs, and DAs must interface with communication devices. Hence, generic but focused interface definitions are required. The IEEE 1900.6 is developing the interfaces and data structures that enable information flow among the various entities.

While spectrum sensing is still considered a core technology for dynamic spectrum access networks, it is recently more and more intended not only as a standalone and real-time technique enabling cognitive devices to fulfill their function, but also a necessary tool to constantly update geolocalized spectrum maps. Spectrum sensing capabilities broadly enabled on distributed mobile or fixed cognitive devices allow monitoring the spectrum occupancy and the overall level of interference with high precision and timeliness. In further evolved schemes, every “object” connected to the Internet could provide sensing features corresponding to its technical capabilities. This approach, which is oriented toward both the Internet of Things (IoT) and green radio communication paradigms, would

create dynamic wide-area maps of spectrum usage rapidly updated to optimize the overall electromagnetic emission and global interference.

Intelligent transportation systems also can support spectrum sensing, potentially enabling dynamic spectrum access and CR in vehicular communications. Buses, taxis, or commuter trains, which periodically repeat their path, can be used as vehicular sensors able to collect periodic information about spectrum usage. In this framework, IEEE 1900.6 is also investigating new proposals that enlarge the standardization process toward including these topics and to comply with emerging future scenarios.

IEEE 1900.6

IEEE 1900.6: AN OVERVIEW

IEEE 1900.6-2011 was published on April 22, 2011. This section summarizes the general structure of the standard to give an overview of the conclusion achieved at the end of the 1900.6 WG activities, leading toward upcoming activities addressing both an extension of the application area as well as enabling existing communication systems to benefit from spectrum sensing. Further details and an in-depth technical report can be found in [11].

IEEE 1900.6 standardizes the information exchange between spectrum sensors and their clients in advanced radio communication systems in a technology-neutral way, which makes it possible to achieve independence from the underlying technology maintaining extensibility and encouraging openness and innovation for further advances in technology. Future amendments to

the standard will address more technology-specific aspects and functionality to achieve broader acceptance of the standard in the scope of current wireless communication systems. The standard specifies a logical model consisting of a number of logical entities: sensors, CEs, and DAs. The latter two are considered clients to sensors. Sensing related information (i.e., sensing data and sensing control information) flows across the corresponding interfaces between sensors and their clients as shown in Fig. 2. The standard explicitly allows sensors to be clients of other sensors, thus satisfying requirements set by certain distributed sensing applications. In addition, the standard also considers configurations having CEs or DAs temporarily taking the role of sensors, considering, for example, DAs to provide stored, archived, or computed sensing related information to clients, or to implement forwarding of regulatory requirements in the course of an information exchange between sensors and their clients. Future extensions to the standard hence will allow interfacing sensors with external entities, such as geolocation databases, by utilizing the DA as a type of proxy.

The standard considers three types of logical interfaces: the interface between spectrum sensors (*S-S* interface), the interface between CE or DA and sensors (*CE/DA-S* interface), and the interface between CEs and DAs (*CE-CE/DA* interface). Since service primitives defined for these interfaces partly overlap in functionality, the resulting logical model includes options to forward sensing related information across multiple realizations of a CE or DA entity, such as in common radio access networks where a CE or DA might be collocated with base stations. A sample system topology highlighting this communication flow and the corresponding realization of interfaces is depicted in Fig. 3.

We note here that IEEE 1900.6 makes no assumptions on a spectrum sensor's implementation. A sensor may be based on an embedded or dedicated radio frequency (RF) device, or realized as an integral part of a CR system able to sense a portion of RF spectrum. A closer look at the current state of the art in RF spectrum sensing considered in developing the standard is given in [12, 13].

In general, spectrum sensors determine — potentially spatio-temporal — spectrum occupancy information. The method a sensor uses to obtain this information from an RF sensing process is defined completely by the internal analysis strategies of sensors and the algorithms available to the sensor. The behavior of sensors might be configured and controlled by its client (e.g., by a CE) to make efficient use of its potential reconfiguration and adaptation capacity. Sensor-internal processing, signal analysis, and data fusion capabilities are explicitly considered an enabling property of sophisticated sensors that will hit the market in the future.

A BRIEF DESCRIPTION OF IEEE 1900.6

In their realization, IEEE 1900.6 logical entities rely on platform services that are by intention not specified further by the standard. Instead, the standard specifies the service access points as well as the data structures exchanged across

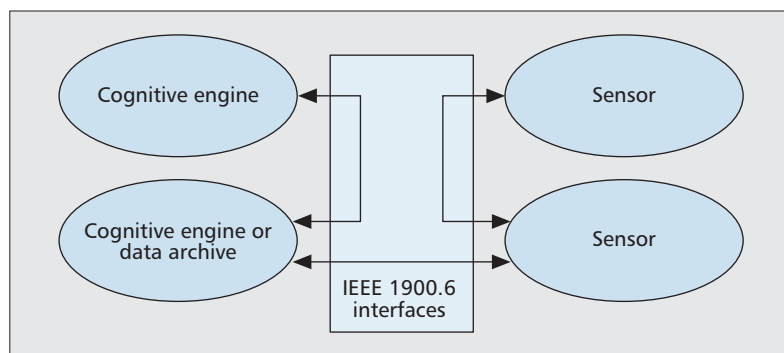


Figure 2. IEEE 1900.6 entities and interfaces.

these service access points. The reference model (Fig. 4) shows that the IEEE 1900.6 specific functionality (summarized as “IEEE 1900.6 services” in Fig. 4) utilizes service access points that have to be realized by platform-specific measurements and communication services. The IEEE 1900.6 services in turn have to provide a service access point to applications that want to make use of spectrum sensing. Hence, logical interfaces are realized through communication services provided by the platform, depending on the logical entity realized and its specific communication demands, set by the application scenario and its specific configuration. Platform services and their service access points are realized by subsystems. Additionally, a platform local client to the sensing services provided by IEEE 1900.6 logical entities is also considered a dedicated subsystem. This is due to the fact that future amendments to the standard may allow utilizing this service access point by IEEE 1900.6 services also to access enhanced platform services providing, for example, sensing data fusion or processing functions.

- The *measurement* subsystem and its service access point are realized by the platform. It represents the device-specific implementation of the platform RF sensing and analysis functionality, usually implemented by a physical RF sensor and its associated sensing data processing capacity. The standard makes no assumption on how the platform implements this service. In particular, the standard does not exclude implementations making use of proprietary communication means to access remote measurements services by the platform.

- The *communication* subsystem summarizes the means provided by the platform to communicate between spectrum sensors and their remote clients. No assumptions are made by the standard on the implementation of the communication subsystem except the functionality of its service access point, which characterizes it as closely related to an open systems interconnection (OSI) layer 4 message transport service. Valid implementations might realize both local (i.e., via some short-range physical connection) as well as remote communications (i.e., via a communication network).

- The *application and control* subsystem in the first place is some abstract user of the IEEE 1900.6 services utilizing the application service access point realized by the 1900.6 services to

A number of recent and upcoming standards have been identified for their potential interaction with the IEEE 1900.6 both in terms of utilizing IEEE 1900.6 services as well as providing functionality that can be used by 1900.6 services.

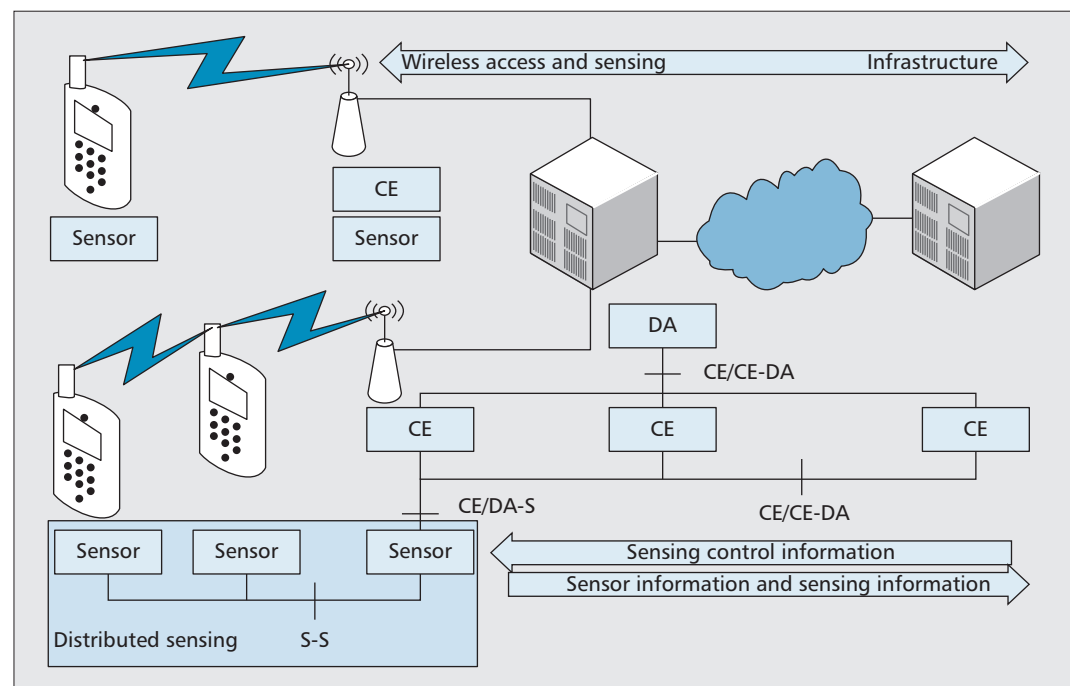


Figure 3. Sample topology of an IEEE 1900.6 distributed RF sensing system.

access spectrum sensing. For example, a control and management entity of a wireless network may access IEEE 1900.6 spectrum sensing services thru this service access point. Vice versa, the IEEE 1900.6 services may access platform-provided services that are none of communication or measurement services through this service access point.

Although covering the most common applications, the reference model of Fig. 4 and hence the role of subsystems described above do not reflect some specific configurations. For example, a DA entity may have no need to realize an application service access point but need to realize a measurement access point instead, providing measurement services as a kind of “virtual sensor” or “legacy gateway.” These application scenarios recently evolved in the course of discussing potential amendments to the standard. They are not considered incorrect use of the current standard, but need further clarification and guidelines for correct use.

A number of recent and upcoming standards have been identified for their potential interaction with the IEEE 1900.6 in terms of both utilizing IEEE 1900.6 services as well as providing functionality that can be used by 1900.6 services. We further elaborate on this later.

The interaction of IEEE 1900.6 logical entities across service access points is realized by a set of service primitives and information elements described by the standard in the form of parameter sets in an implementation-independent way. The concise specification of these parameter sets, denoted as “sensing related information,” provides the core of the IEEE 1900.6 standard. A description of the information flow between IEEE 1900.6 entities, each assuming the role of either a sensor or a client in the course of a transaction, is provided by the standard based on the exchange of such sensing

related information. Herein, sensing related information basically consists of four categories: sensing information, sensing control information, sensor information, and regulatory requirements.

- *Sensing information* denotes any measurement information that can be obtained from a spectrum sensor.
- *Sensing control* denotes any information required to describe the status or configuration, and to control or configure the data acquisition and RF sensing process of a spectrum sensor.
- *Sensor information* denotes the parameters used to describe the capabilities of a spectrum sensor.
- *Regulatory requirements* are unique to the application area of dynamic spectrum access by CRs.

As set by IEEE 1900.6, sensing information includes any related spatiotemporal state information such as position, time, or confidence of acquisition. It may consist of basic measurement values such as signal/noise power levels along with the related descriptive information such as measurement bandwidth and center frequency. Depending on a sensor’s capabilities and algorithms, available sensing information may also consist of more complex descriptions of the observed RF environment such as signal type, modulation type, and traffic pattern of the detected remote spectrum user. In a distributed sensing scenario this sensing information may be the outcome of multiple spatially distributed RF sensing processes.

Sensing control information is not much different from the sensing information, sharing most of the basic information elements (i.e., parameters), but is mainly used in the course of exchanging control commands. For example, RF bandwidth and center frequency are sensing information in conjunction with the measured

data obtained from a sensor, but they act as sensing control information when used for tuning the spectrum sensor into a new measurement process. Depending on the sensing capabilities of a sensor, sensing control information may become more complex and descriptive (i.e., describing a sensing strategy rather than setting a single sensing parameter) as in, for example, setting the scanning scheme within a given upper and lower frequency bound using a certain sweep and sojourn time for each intermediate scan step attained.

Sensor information can be requested from a spectrum sensor to learn about its properties, usually describing its limitations of operation in the form of operational parameters such as frequency range, accuracy, and similar objectives. In this context, a client may also obtain the sensor's absolute limits of operation by requesting the sensor's electronic data sheet prepared by the sensor manufacturer. It should be noted here that the data sheet providing sensor information is considered complementary since real operational limits and confidence achieved by a spectrum sensor very much depend on the current operating conditions as well as on the RF environment describing the current operational context.

Regulatory requirements are expressed by the same sensing and sensing control parameters discussed above, but they denote obligations of a spectrum sensor rather than measurement or control parameters. They may be used to control and configure a spectrum sensor, but may also be used to evaluate if a sensor satisfies given demands in terms of accuracy, confidence, granularity, sensitivity, and so on. Hence, there is only a fuzzy boundary between regulatory requirements expressed as a set of sensing related parameters and regulatory policies.

IEEE 1900.6-2011 provides a sound baseline for a standardized information exchange between spectrum sensors and their clients. It clearly goes beyond a mere specification of physical communication between sensing equipment and RF context analysis, and provides a logical and architectural view to the logical entities, services, and interfaces involved in a distributed spectrum sensing process. Although its neutrality with respect to enabling technologies makes it versatile in use, it certainly can be enhanced in terms of specifications that allow users of the standard to verify and prove conformance of their specific application of the IEEE 1900.6 standard. This will be a main objective of future releases and amendments to the standard.

RELATION WITH OTHER RELATED STANDARDIZATION EFFORTS

The following standards generally consider spectrum sensors and related interfaces as an integral part of the system they define. A generalized approach as provided by IEEE 1900.6 thus must be seen as a complementary method to obtain spectrum usage information and, consequently, is mainly seen as an impetus. Mature standards will be able to benefit significantly upon the acceptance of IEEE 1900.6 by hardware manu-

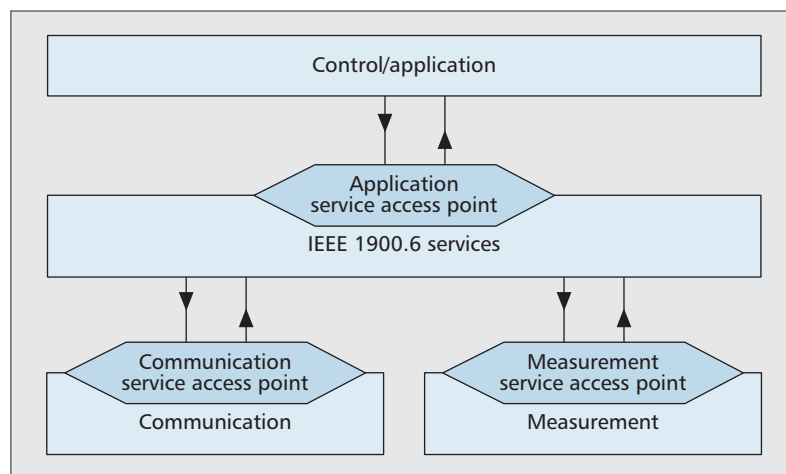


Figure 4. IEEE 1900.6 reference model.

facturers.

Within the framework of the IEEE, the IEEE 802.15 WG for Wireless Personal Area Networks works 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. The IEEE 802.19 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 applied to other unlicensed wireless systems. The definition of the coexistence metrics can be facilitated by clear standardization of the data structure provided by IEEE 1900.6.

The IEEE 802.22 WG on Wireless Regional Area Networks, launched in 2005, is also based on CR in the TV white space spectrum [14]. The physical and MAC layers of IEEE 802.22 are similar to IEEE 802.16 with the amendments related to the identification of incumbent spectrum users and defining the power levels so as not to interfere with the adjacent bands. Coexistence with incumbents is guaranteed by a sense-and-avoid approach. IEEE 802.22 WG activities will benefit from a clear definition of the data structure and information to be exchanged between base station (BS) and customer premises equipment (CPE) to perform distributed sensing, making the IEEE 1900.6 standard definition a concrete task.

In December 2008, a new group called the Cognitive Networking Alliance (CogNeA) was initiated. This group is composed of Philips, Samsung, HP, ETRI, GeorgiaTech, and Motorola. CogNeA aims to drive the definition and adoption of industry-wide standards for low-power personal and portable wireless devices to operate in the TV white spaces. In this regard, a new standard was created in the framework of the European Computer Manufacturers Association (ECMA) in December 2009. This standard (ECMA 392) covers "PHY and MAC for Operation in TV White Space." The standard target applications are high-speed video streaming and Internet access on personal/portable electronics, home electronics equipment, and computers and peripherals [15].

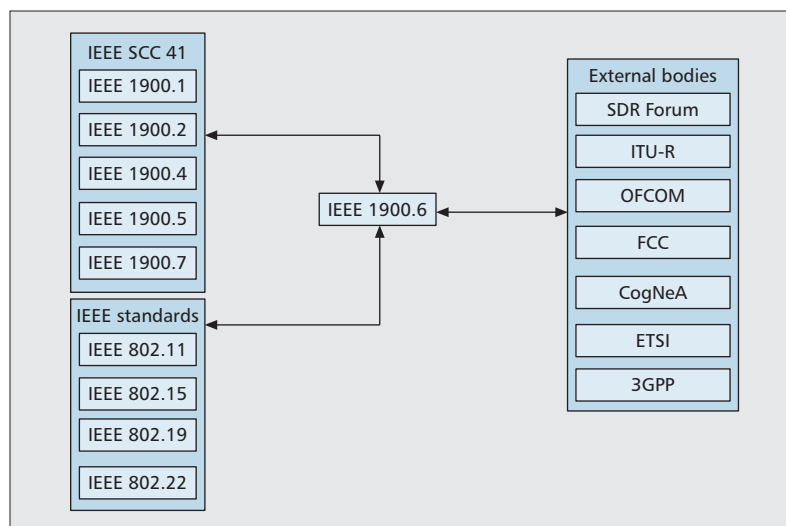


Figure 5. Liaison between IEEE 1900.6 and other standardization activities.

The Wireless Innovation Forum (WInnF), formerly the Software Defined Radio (SDR) Forum, is also involved in several activities related to CRs, cognitive networks (CNs), and DSA. The CR WG from WInnF is devoted to the preparation of a literature survey to identify and present quantifiable metrics that objectively measure the benefits of CR technology. A first release of this report is expected soon. The WIF has many committees catering to the standardization of SDR, such as User Requirements, Regulatory, Advanced Wireless Networking and Infrastructure, Next Generation Radio Technologies, and the Coordinating Committee on International SCA Standards. These committees have interest groups and work groups, which concentrate on specific issues under these committees [16].

In February 2008, the European Telecommunications Standards Institute (ETSI) started a new technical committee on reconfigurable radio systems (RRS), with liaison with IEEE DYSpan-SC 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 a draft related to technical recommendations, DTR/RRS-01003, "Spectrum Aspects of Cognitive Radio and Software Defined Radio Systems." WG2 issued the recommendation DTR/RRS-02004, "Multiradio Interface for Software Defined Radio Mobile Device Architecture and Services." Both these recommendations deal with aspects related to spectrum sensing issue, but do not specify how information exchange between devices should be handled. IEEE 1900.6 could be used in this sense.

The Third Generation Partnership Project (3GPP) is also interested in standardizing CR-like features in its future releases. In particular, 3GPP plans to enhance the Long Term Evolution standard (radio interface of the Universal Mobile Telecommunications System, UMTS) in Release 10 with CR functionalities. For example, the idea of a cognitive reference signal is proposed through which each access network (AN)

can broadcast interference level, frequency bands, radio access technologies of other networks, and other information, which can help newly joined user equipment to choose the best RAN. Within this framework, a clear definition of logical interfaces and supporting data structures for information exchange between entities provided by IEEE 1900.6 can contribute to the fast deployment of such a new cognitive cellular system. Figure 5 and Table 1 summarize the relation between the IEEE 1900.6 WG and other standardization activities.

OPEN ISSUES FOR STANDARDIZATION AND FUTURE OUTLOOK

Although IEEE 1900.6 is now complete and published, there are still some open issues that could potentially be addressed in future activities of the working group. One of them is the contribution on standardization of geolocation databases for cognitive access systems. Location databases have some history in different areas such as traffic information and geodesic applications. The Open, Compact and Royalty-free Dynamic Location Referencing (OpenLR™) project [17] and the Transport Protocol Experts Group (TPEG-LOC) [18] are very active within this framework. OpenLR is an open source software project launched by TomTom International B.V. in September 2009. This project provides a royalty-free dynamic location referencing method that enables reliable data exchange and cross-referencing using digital maps of different vendors and versions. TPEG has specified a number of data formats and protocols in the ITS context. TPEG LOC is a subset specifically addressing portable location referencing. It is an XML-based structure, and can be augmented by proprietary data types and combined with other TPEG specifications. TPEG originally comes from the broadcasters' area, providing, for example, road traffic information.

As described in [19], one way to implement cognitive technologies is to use geolocation databases. Using such databases gives rise to a number of regulatory issues. The CR device will need to know its position. The data concerning spectrum used in each location would have to be provided (e.g., by either the existing users, regulators, or a specific entity). There will be associated costs in collecting and editing the information to be provided. The entity who will need to bear the costs could be the regulator, external database owners, or CR users.

There will be issues associated with access to, and availability and reliability of the database (update rate, access policies, etc.), and operational and management issues (security, integrity, privacy, etc.) linked to the databases. An issue where a harmonized approach is desirable for CR devices is to have standardized protocols/languages to access the database and format of data within the database (database profile). This would allow CR devices to establish connection to the database and download the rules from the database to allow correct operation in the country in which it is operating, even though the rules may vary across countries. The latter

Name of the standard	Scope	Relation with IEEE 1900.6
IEEE 1900.1	Providing common definitions of terms and concepts	Complementary
IEEE 1900.2	Describing all aspects of a framework for analyzing the interference and coexistence between different wireless systems	Complementary
IEEE 1900.4	Defining the architecture and addresses DSA operational issues in heterogeneous wireless networks	Complementary
IEEE 1900.5	Defining requirements for 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	Complementary
IEEE 1900.7	Developing a standard that defines radio interface (MAC and PHY layers) for white space communication systems	Complementary
IEEE 802.19	Defines general coexistence metrics for all IEEE 802 networks working in the unlicensed bands	Requires information exchange between devices
IEEE 802.22	Aimed at using cognitive radio (CR) techniques to allow sharing of geographically unused spectrum allocated to the television broadcast service	Requires information exchange between devices
CogNeA ECMA 392	PHY and MAC for operation in TV white spaces	Requires information exchange between devices
ETSI DTR/RRS-01003/02004	Spectrum aspects of cognitive radio and multiradio interface for SDR mobile device architecture and services	Requires information exchange between devices
3GPP-LTE- Rel. 10	Plans to enhance LTE standard (radio interface of the UMTS) with CR functionalities	Requires information exchange between devices

Table 1. Relationship with other standardization activities.

question could be a challenging topic for the IEEE 1900.6 WG. In particular, the exchange of sensing information between 1900.6 entities and the database might be in focus.

Enabling the database approach requires the database to be populated and devices to be able to interact with the database in a prescribed manner. How a database can be populated and maintained by using sensors is an interesting issue. The data archive entity here may play an important role in processing sensor data prior to handing it over to the database.

CR devices are expected to send a request to the database which includes their current location for the database to respond with details of channels that are available in the vicinity and associated power levels that are allowed. The devices might indicate the radius around them for which they require information — for example a small radius such as 100m would return only information about channels in that specific location whereas a larger radius such as 10km would allow the device to download a portion of the database such that if it moved, or had poor locational accuracy, it would not need to re-consult the database.

In order to perform this analysis the database will need to have details of all the licensed transmitters in the spectrum including information such as transmitter height, power levels and for PMSE information such as whether the devices are located indoors. It will then need to use agreed propagation algorithms coupled with

mapping and terrain databases to perform the predictions. This seems to be important since the database has no information about the RF system used. The information is only available at the front-end. Both directions of information flow (between sensors and database) thus need to be filtered by processing at the sensors. Further discussion and consultation is required in areas such as the information should be provided by the license holders, the propagation algorithms which should be used and the parameters that should be assumed for device sensitivity and selectivity.

The devices will need to use a predetermined protocol to report their location and required radius of information to the database and to understand the response from the database. This may be better standardized by industry than the regulator [19]. In any case, a joint standardization activity between industrial partners and national or international actors would easily be hosted and supported within the activity of IEEE 1900.6. In that sense the statement given by OFCOM in [20] is emblematic:

“Much of the work on cognitive access to date has been on sensing with research only relatively recently moving to geo-location as the difficulties with sensing became increasingly clear. As a result, the body of knowledge around geo-location is less well developed and we felt unable to conclude on appropriate mechanisms at the time of the July 2009 statement. Since that time further work has been undertaken both in the UK and other coun-

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tries, notably the US. We have monitored and influenced this work and have also held discussions with relevant stakeholders across a wide range of issues. We now believe that it would be helpful to clearly set out the open issues and some of our thinking in these areas. It is quite likely that some of the areas discussed here will be standardized by others, or that manufacturers may adopt proprietary approaches, but we believe that by clarifying and identifying the issues we will be able to assist in the development of a geo-location approach, delivering on our duties to further the interests of citizens and consumers by securing the optimal use of spectrum through encouraging innovation."

Since a wide range of devices from different manufacturers can all successfully access the database, when defining a geolocation approach it is important to define the type and format of information to be exchanged between the devices and the database. The key geolocation issues, that is, the information to be provided by the device to the database(s), should be flexible, allowing the CR device to select from providing only its location through to providing location, locational accuracy, device type, and preferences as to the amount of information it can receive. As the device provides additional information, the database can tailor its response, in some cases allowing higher power levels. We note that this may require substantial standardization work around the protocols to be used. Once again, the two-year P1900.6 WG study and activities on data structure and sensing interfaces can be a solid starting point to define the protocols to be used for the information exchange between CR devices and geolocated databases.

CONCLUSIONS

In this article, the efforts of the IEEE 1900.6 WG are introduced. Within the framework of IEEE DySPAN-SC, a general overview of the activities of the WG, including its goals and an outline of the current standard, is provided. IEEE Standard 1900.6-2011 has been introduced thoroughly but in a nutshell. Its relationship and interaction, and possible influences of the ongoing standardization activity with respect to other similar standardization initiatives on CR systems are also analyzed. Further open issues, with special emphasis on geolocation features of CR, have been investigated so as to offer new perspectives to researchers, standardization bodies, and organizations working on CR.

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