



IEEE Standard Definitions and Concepts for Dynamic Spectrum Access: Terminology Relating to Emerging Wireless Networks, System Functionality, and Spectrum Management

IEEE Communications Society

Sponsored by the
IEEE Standards Coordinating Committee 41 on
Dynamic Spectrum Access Networks

IEEE
3 Park Avenue
New York, NY 10016-5997, USA
26 September 2008

IEEE Std 1900.1™-2008

IEEE Standard Definitions and Concepts for Dynamic Spectrum Access: Terminology Relating to Emerging Wireless Networks, System Functionality, and Spectrum Management

Sponsor

IEEE Communications Society

and

**IEEE Standards Coordinating Committee 41 on
Dynamic Spectrum Access Networks**

Approved 12 June 2008

IEEE-SA Standards Board

Abstract: This standard provides definitions and explanations of key concepts in the fields of spectrum management, cognitive radio, policy-defined radio, adaptive radio, software-defined radio, and related technologies. The document goes beyond simple, short definitions by providing amplifying text that explains these terms in the context of the technologies that use them. The document also describes how these technologies interrelate and create new capabilities while at the same time providing mechanisms supportive of new spectrum management paradigms such as dynamic spectrum access.

Keywords: cognitive radio, cognitive radio networks, dynamic spectrum access, policy-based radio, software-controlled radio, software-defined radio, spectrum management

The Institute of Electrical and Electronics Engineers, Inc.
3 Park Avenue, New York, NY 10016-5997, USA

Copyright © 2008 by the Institute of Electrical and Electronics Engineers, Inc.
All rights reserved. Published 26 September 2008. Printed in the United States of America.

IEEE and 802 are registered trademarks in the U.S. Patent & Trademark Office, owned by The Institute of Electrical and Electronics Engineers, Incorporated.

PDF: ISBN 978-0-7381-5776-4 STD95810
Print: ISBN 978-0-7381-5777-1 STDPD95810

No part of this publication may be reproduced in any form, in an electronic retrieval system or otherwise, without the prior written permission of the publisher.

IEEE Standards documents are developed within the IEEE Societies and the Standards Coordinating Committees of the IEEE Standards Association (IEEE-SA) Standards Board. The IEEE develops its standards through a consensus development process, approved by the American National Standards Institute, which brings together volunteers representing varied viewpoints and interests to achieve the final product. Volunteers are not necessarily members of the Institute and serve without compensation. While the IEEE administers the process and establishes rules to promote fairness in the consensus development process, the IEEE does not independently evaluate, test, or verify the accuracy of any of the information contained in its standards.

Use of an IEEE Standard is wholly voluntary. The IEEE disclaims liability for any personal injury, property or other damage, of any nature whatsoever, whether special, indirect, consequential, or compensatory, directly or indirectly resulting from the publication, use of, or reliance upon this, or any other IEEE Standard document.

The IEEE does not warrant or represent the accuracy or content of the material contained herein, and expressly disclaims any express or implied warranty, including any implied warranty of merchantability or fitness for a specific purpose, or that the use of the material contained herein is free from patent infringement. IEEE Standards documents are supplied “AS IS.”

The existence of an IEEE Standard does not imply that there are no other ways to produce, test, measure, purchase, market, or provide other goods and services related to the scope of the IEEE Standard. Furthermore, the viewpoint expressed at the time a standard is approved and issued is subject to change brought about through developments in the state of the art and comments received from users of the standard. Every IEEE Standard is subjected to review at least every five years for revision or reaffirmation. When a document is more than five years old and has not been reaffirmed, it is reasonable to conclude that its contents, although still of some value, do not wholly reflect the present state of the art. Users are cautioned to check to determine that they have the latest edition of any IEEE Standard.

In publishing and making this document available, the IEEE is not suggesting or rendering professional or other services for, or on behalf of, any person or entity. Nor is the IEEE undertaking to perform any duty owed by any other person or entity to another. Any person utilizing this, and any other IEEE Standards document, should rely upon the advice of a competent professional in determining the exercise of reasonable care in any given circumstances.

Interpretations: Occasionally questions may arise regarding the meaning of portions of standards as they relate to specific applications. When the need for interpretations is brought to the attention of IEEE, the Institute will initiate action to prepare appropriate responses. Since IEEE Standards represent a consensus of concerned interests, it is important to ensure that any interpretation has also received the concurrence of a balance of interests. For this reason, IEEE and the members of its societies and Standards Coordinating Committees are not able to provide an instant response to interpretation requests except in those cases where the matter has previously received formal consideration. At lectures, symposia, seminars, or educational courses, an individual presenting information on IEEE standards shall make it clear that his or her views should be considered the personal views of that individual rather than the formal position, explanation, or interpretation of the IEEE.

Comments for revision of IEEE Standards are welcome from any interested party, regardless of membership affiliation with IEEE. Suggestions for changes in documents should be in the form of a proposed change of text, together with appropriate supporting comments. Comments on standards and requests for interpretations should be addressed to:

Secretary, IEEE-SA Standards Board
445 Hoes Lane
Piscataway, NJ 08854
USA

Authorization to photocopy portions of any individual standard for internal or personal use is granted by the Institute of Electrical and Electronics Engineers, Inc., provided that the appropriate fee is paid to Copyright Clearance Center. To arrange for payment of licensing fee, please contact Copyright Clearance Center, Customer Service, 222 Rosewood Drive, Danvers, MA 01923 USA; +1 978 750 8400. Permission to photocopy portions of any individual standard for educational classroom use can also be obtained through the Copyright Clearance Center.

Introduction

This introduction is not part of IEEE Std 1900.1-2008, IEEE Standard Definitions and Concepts for Dynamic Spectrum Access: Terminology Relating to Emerging Wireless Networks, System Functionality, and Spectrum Management.

This standard establishes common terminology for describing emerging networks and nodes employing radio devices characterized by cognition, adaptation, environment awareness, and policy-based adaptive techniques. Specifically, the definitions provided in this document stem predominantly from a spectrum management point of view. It is anticipated that these definitions will ultimately mature and ideally achieve widespread acceptance among researchers, manufacturers, service providers, regulators, and operators.

The intent of this document is to promote a common understanding of systems technology and spectrum management terms so that technologists in a variety of fields such as radio science, including digital communications, computer science, and artificial intelligence, and regulators have a common understanding of the terminology. It is the intent of this document to provide concise definitions of key terms in advanced radio system technologies and in advanced spectrum management techniques.

The focus of this standard is on terms and concepts relating to emerging wireless networks, radio, technology, system functionality, and spectrum management. It was agreed that in some cases, multiple definitions for a specific term were appropriate. Development of this standard required:

- a) The creation of some new terms (e.g., cognitive radio) and the development of definitions for these new terms.
- b) The development of alternative definitions for existing terms (e.g., dynamic frequency selection) that have been defined by other standards development organizations; these alternative definitions were required for next-generation radio and spectrum management because these terms have new meanings when used in the context of discussing advanced radio systems.

It is deemed to be outside the focus of this standard to include all of the terms relevant to wireless communications systems and spectrum management (e.g., radio frequency and radio signal). However, when deemed appropriate, existing terms from the ITU-R and other IEEE documents are included for the convenience of the reader even though the term and definition is unchanged for next-generation radio and spectrum management. These terms are clearly identified in the text.

This document provides normative terms and definitions to support the research and deployment of dynamic spectrum management (DSM) and dynamic spectrum access (DSA). Many factors are creating a need for DSM and DSA. Among the forces creating this need for change are as follows:

- The increasing use of wireless services and their need for spectrum.
- The increasing data load being transmitted wirelessly, requiring increasing spectrum bandwidth.
- The emergence of multimode products such as mobile, broadcast, and radiolocation into single devices.
- Increasing pressure to guarantee spectrum access for priority services such as public safety while allowing other uses for that same spectrum when not in use by those priority services.

Overview of New Technologies

Terminology used to describe equipment, systems, and networks employing advanced radio functionality are contained within this standard that will provide researchers, manufacturers, service providers, regulators, operators, and users with the means of describing advanced radio devices and spectrum management techniques. Some of the general features of these emerging radio and wireless networking systems are as follows:

- Flexibility
- Dynamic and adaptive behavior
- Awareness (e.g., location and radio environment), cognition, and intelligence
- Networking for group collaboration and interaction (e.g., sensing the spectrum usage environment)

These features create many new avenues for improving use and access to the radio spectrum. Specifically, they provide additional degrees of freedom that allow a device to choose the best method of spectrum access for a particular situation and to alter the method of access to respond to changing conditions. For example, dynamic spectrum access systems have been suggested as a fundamental, technology-enabled method to make more effective and efficient use of scarce available spectrum. In principle, the DSA concept advocates empowering radio systems with the local authority and responsibility to manage available spectrum. However, practical methods for designing, developing, and managing such systems remain in the early formative stages. Current spectrum management practices do not provide effective techniques for certifying these types of advanced radio devices or for managing their access to the radio spectrum. This situation could create barriers to the introduction of new radio technologies if resolution of spectrum issues for each new device must be addressed on a case-by-case basis.

Recent advancements in wireless communication technology have given rise to many new terms and concepts within the body of technical literature, including reconfigurable radio, software-defined radio, software-controlled radio, policy-defined radio, adaptive radio, cognitive radio, and others. Although radios certainly play an important part in the design and construction of wireless communication systems, these advanced technologies extend beyond what is commonly thought of as a “radio.” When describing these technologies, therefore, it is more useful to consider them in the context of a complete communications system or network.

For example, the terms “cognitive radio” and “adaptive radio” are often used, and although it may be a convenient linguistic construct, it is unclear that the use of these terms is always both linguistically and logically correct. In wireless communication systems, radios are physical devices that transmit and receive information encoded on radio-frequency (RF) waveforms using antennas, transmitters, and receivers. That is, radios are designed to perform certain functions, for example, receiving and transmitting. The development of this standard was founded on the premise that wireless communication systems will evolve to the point where cognitive and adaptive functionality play an important, essential role in their use of the radio spectrum, and that the industry is now approaching that point in history. Consequently, this standard provides definitions for terms describing this expanded functionality that are relevant to spectrum use by next-generation radios and networks. For example, the cognition function may not be just a radio function as radio is defined herein; some of the functionality may lie outside the radio itself. This focus is provided throughout the standard.

The term “cognitive” has recently entered into the lexicon of wireless networks in an attempt to describe a functionality that is inherently distributed within not only a given network but also potentially a network of networks. Consider, for example, a network of unlicensed band WiFi* access points and stations providing Internet access for the population of a metropolitan area, operating alongside a public safety network,

* WiFi is a mark of the Wi-Fi Alliance.

including police, fire, and ambulance communications in the same band, with both networks sharing information that allows them to coexist. This new cognitive functionality provides a mechanism for *peaceful coexistence* among multiple networks and the potential for *equitable sharing* of RF spectrum. As the term “cognitive” implies, at the heart of the new technology is *knowledge*, that is, information that is gathered and stored in possibly a distributed manner throughout the network of networks. The concepts of collaboration and consent are equally important; that is, some policy agreement exists that defines the objectives and constraints of the participating networks (cf. policy-based radios). Throughout this standard, that cognitive and related functionality may be shared throughout the network, network nodes, and the radios in the network nodes. No attempt is made to define exactly how these functions are distributed because that is an implementation issue.

Virtually all radios on the market today use some form of digital signal processing involving a microprocessor and software of some form to perform even the simplest function (e.g., changing the operating frequency). Yet, the term “software-defined radio” is commonly used to distinguish a certain class of radios, and usually it is meant to convey a meaning that goes beyond merely implying the existence of some software in the device. The term is used to describe certain functionality that is performed or managed differently because it is driven by software rather than by hardware.

It is important to realize that communications nodes and networks with primitive cognitive, adaptive, and software-defined functionality exist today. The current IEEE 802.11a/b/g standard specifies a Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA) Media Access Control (MAC) protocol that involves a “stop, look and listen ... watch out for the cars” cognitive functionality. It is inherently adaptive and can be instantiated in software. This represents the early stages of an advanced and evolving communications technology with objectives including the ability to offer more robust, maximum-channel capacity usage, increased spectrum-usage efficiency, as well as fault-tolerant and ubiquitous information-conveyance capabilities for one or more users. Communication nodes and networks with cognitive functionality can potentially use contextual information to devise and implement solutions that ideally best serve the current and anticipated information transfer requirements. This contextual information can be derived from the physical (node state and device resources, spatial, environmental, network topology, and communications channel information), regulatory and policy (frequency spectrum usage rules and etiquettes, licenses, user access rights), social (individualistic or collaborative and distributed network existence), and economic (payment mechanisms, spectrum market environment) domains.

In the framework of wireless networks, whether it is a portion of the network or the entire network, network management procedures imply the management of the available transmission spectrum, which in turn impacts system performance, resource allocation, quality-of-service, and so on. To this extent, network management is directly related to spectrum management; therefore, comprehension of network management concepts is necessary when discussing spectrum management.

In this standard, some terms are related (i.e., some terms are defined and then used in the definitions of other terms). Terms that appear in the definition of other terms are placed in **bold** in the definition for the higher level term (see, for example, the term **software-defined radio** and the term **software defined**).

Notice to users

Laws and regulations

Users of these documents should consult all applicable laws and regulations. Compliance with the provisions of this standard does not imply compliance to any applicable regulatory requirements. Implementers of the standard are responsible for observing or referring to the applicable regulatory requirements. IEEE does not, by the publication of its standards, intend to urge action that is not in compliance with applicable laws, and these documents may not be construed as doing so.

Copyrights

This document is copyrighted by the IEEE. It is made available for a wide variety of both public and private uses. These include both use, by reference, in laws and regulations, and use in private self-regulation, standardization, and the promotion of engineering practices and methods. By making this document available for use and adoption by public authorities and private users, the IEEE does not waive any rights in copyright to this document.

Updating of IEEE documents

Users of IEEE standards should be aware that these documents may be superseded at any time by the issuance of new editions or may be amended from time to time through the issuance of amendments, corrigenda, or errata. An official IEEE document at any point in time consists of the current edition of the document together with any amendments, corrigenda, or errata then in effect. In order to determine whether a given document is the current edition and whether it has been amended through the issuance of amendments, corrigenda, or errata, visit the IEEE Standards Association Web site at <http://ieeexplore.ieee.org/xpl/standards.jsp>, or contact the IEEE at the address listed previously.

For more information about the IEEE Standards Association or the IEEE standards development process, visit the IEEE-SA Web site at <http://standards.ieee.org>.

Errata

Errata, if any, for this and all other standards can be accessed at the following URL: <http://standards.ieee.org/reading/ieee/updates/errata/>. Users are encouraged to check this URL for errata periodically.

Interpretations

Current interpretations can be accessed at the following URL: <http://standards.ieee.org/reading/ieee/interp/>.

Patents

Attention is called to the possibility that implementation of this standard may require use of subject matter covered by patent rights. By publication of this standard, no position is taken with respect to the existence or validity of any patent rights in connection therewith. A patent holder or patent applicant has filed a statement of assurance that it will grant licenses under these rights without compensation or under reasonable rates, with reasonable terms and conditions that are demonstrably free of any unfair discrimination to applicants desiring to obtain such licenses. Other Essential Patent Claims may exist for which a statement of assurance has not been received. The IEEE is not responsible for identifying Essential Patent Claims for which a license may be required, for conducting inquiries into the legal validity or scope of Patents Claims, or determining whether any licensing terms or conditions are reasonable or non-discriminatory. Further information may be obtained from the IEEE Standards Association.

Participants

At the time this standard was completed, the P1900.1 Working Group had the following membership:

James Hoffmeyer, *Chair*
Dennis Stewart, *Vice Chair*
Dennis Stewart, *Secretary*

H. Stephen Berger
Bernard C. Eydt
Frederick Frantz
Fabrizio Granelli
Kalle Kontson

David Murotake
Keith Nolan
Przemyslaw Pawelczak
R. Venkatesha Prasad

Richard Roy
Mark Scoville
Douglas Sicker
Darcy Swain
Peter Tenhula

The following members of the individual balloting committee voted on this recommended practice. Balloters may have voted for approval, disapproval, or abstention.

Kwok Shum Au
Phillip Barsky
Bradford Benbow
H. Stephen Berger
William Byrd
John Chapin
Yi-Ming Chen
Aik Chindapol
Keith Chow
Thomas Dineen
Carlo Donati
Vern Dubendorf
Marc Emmelmann
Bernard C. Eydt
Bruce Fette
Andre Fournier
Prince Francis
Frederick Frantz
Avraham Freedman
Mariana Goldhamer
Fabrizio Granelli
Randall Groves

Edward Hare
Werner Hoelzl
James Hoffmeyer
Stuart Holoman
Daniel Hoolihan
Sergiu Iordanescu
Raj Jain
Poitr Karocki
Kalle Kontson
Thomas Kurihara
Arthur Light
William Lumpkins
Peter Martini
Edward McCall
Gary Michel
Apurva Mody
Ronald G. Murias
David Murotake
Michael S. Newman
Paul Nikolich
Keith Nolan

Donald Parker
Przemyslaw Pawelczak
Subburajan Ponnuswamy
R. Venkatesha Prasad
Leonard Pucker
Maximilian Riegel
Robert Robinson
Richard Roy
Michael Rush
John Sargent
Mark Scoville
Thomas Starai
Dennis Stewart
Walter Struppler
Alourdes Sully
Darcy Swain
Peter Tenhula
Thomas Tullia
Aron Viner
Barry Wallen
Stephen Whitesell
Kevin Zheng Zhang

When the IEEE-SA Standards Board approved this standard on 12 June 2008, it had the following membership:

Robert M. Grow, *Chair*
Tom A. Prevost, *Vice Chair*
Steve M. Mills, *Past Chair*
Judith Gorman, *Secretary*

Victor Berman
Richard DeBlasio
Andrew Drozd
Mark Epstein
Alexander Gelman
William R. Goldbach
Arnold M. Greenspan
Kenneth S. Hanus

James Hughes
Richard H. Hulett
Young Kyun Kim
Joseph L. Koepfinger*
John Kulick
David J. Law
Glenn Parsons
Ronald C. Petersen

Chuck Powers
Narayanan Ramachandran
Jon Walter Rosdahl
Anne-Marie Sahazizian
Malcolm V. Thaden
Howard L. Wolfman
Don Wright

*Member Emeritus

Also included are the following nonvoting IEEE-SA Standards Board liaisons:

Satish K. Aggarwal, *NRC Representative*

Michael H. Kelley, *NIST Representative*

Don Messina

IEEE Standards Program Manager, Document Development

Matthew J. Ceglia

IEEE Standards Program Manager, Technical Program Development

Contents

1. Overview	1
1.1 Scope	1
1.2 Purpose	1
1.3 Flow of the document	2
2. Definitions of advanced radio system concepts	2
2.1 Adaptive radio	2
2.2 Cognitive radio	2
2.3 Hardware-defined radio (see hardware radio)	3
2.4 Hardware radio	3
2.5 Intelligent radio	3
2.6 Policy-based radio	3
2.7 Reconfigurable radio	3
2.8 Software-controlled radio	4
2.9 Software-defined radio	4
3. Definitions of radio system functional capabilities	4
3.1 Adaptive modulation	4
3.2 Cognitive control mechanism	5
3.3 Frequency agility	5
3.4 Geolocation capability	5
3.5 Location awareness	5
3.6 Policy-based control mechanism	5
3.7 Radio awareness	6
3.8 Software controlled	6
3.9 Software defined	6
3.10 Transmit power control	6
4. Definitions of network technologies that support advanced radio system technologies	6
4.1 Cognitive radio network	6
4.2 Composite network	6
4.3 Reconfigurable networks	7
4.4 Dynamic spectrum access networks	7
5. Spectrum management definitions	7
5.1 Allocation	7
5.2 Clear channel assessment function	7
5.3 Coexistence	7
5.4 Coexistence mechanism	7
5.5 Cognitive interference avoidance	8
5.6 Collaboration	8
5.7 Collaborative decoding	8
5.8 Collaborative spectrum usage	8
5.9 Communications mode	8
5.10 Prioritized spectrum access	8
5.11 Distributed radio resource usage optimization	8
5.12 Dynamic channel assignment	9

5.13 Dynamic frequency selection	9
5.14 Dynamic frequency sharing.....	9
5.15 Dynamic spectrum access.....	9
5.16 Dynamic spectrum assignment.....	9
5.17 Dynamic spectrum management	10
5.18 Electromagnetic compatibility.....	10
5.19 Frequency hopping.....	10
5.20 Frequency sharing	10
5.21 Hierarchical spectrum access	10
5.22 Horizontal spectrum sharing	10
5.23 Interference.....	11
5.24 Interference event.....	11
5.25 Interoperability	11
5.26 Negotiated spectrum access.....	11
5.27 Noncollaborative coexistence mechanism.....	11
5.28 Opportunistic spectrum access	11
5.29 Opportunistic spectrum management	12
5.30 Performance metric	12
5.31 Policy traceability.....	12
5.32 Precedence assertion.....	12
5.33 Protocol agility.....	12
5.34 Quality of service	13
5.35 Quality-of-service management	13
5.36 Radio quiet zone.....	13
5.37 Restricted dynamic spectrum access etiquette.....	13
5.38 Spatial awareness	13
5.39 Spectral opportunity	14
5.40 Spectrum access	14
5.41 Spectrum access behavior	14
5.42 Spectrum availability beacon	14
5.43 Spectrum broker	14
5.44 Spectrum efficiency.....	15
5.45 Spectrum etiquette.....	15
5.46 Spectrum leasing	15
5.47 Spectrum management	15
5.48 Spectrum overlay.....	15
5.49 Spectrum owner.....	15
5.50 Spectrum pooling	15
5.51 Spectrum sensing.....	16
5.52 Spectrum sharing.....	16
5.53 Spectrum underlay.....	16
5.54 Spectrum utilization	16
5.55 Spectrum utilization efficiency.....	17
5.56 Unrestricted dynamic spectrum access etiquette	17
5.57 Vertical spectrum sharing.....	17
5.58 Wireless network efficiency	17
6. Glossary of ancillary terminology	18
6.1 Air interface.....	18
6.2 Firmware	18
6.3 Machine learning.....	18
6.4 Machine-understandable policies	18
6.5 Interference temperature.....	19
6.6 Ontology.....	19
6.7 Policy.....	19
6.8 Quality of spectral detection.....	19

6.9 Radio	19
6.10 Radio node.....	20
6.11 Radio spectrum.....	20
6.12 Receiver.....	20
6.13 Software	20
6.14 Transmitter	21
6.15 Waveform.....	21
Annex A (informative) Implications of advanced radio system technologies for spectrum management ..	22
Annex B (informative) Explanatory notes on advanced radio system technologies and advanced spectrum management concepts.....	25
Annex C (informative) List of acronyms and abbreviations	44
Annex D (informative) Bibliography	47

IEEE Standard Definitions and Concepts for Dynamic Spectrum Access: Terminology Relating to Emerging Wireless Networks, System Functionality, and Spectrum Management

IMPORTANT NOTICE: This standard is not intended to assure safety, security, health, or environmental protection in all circumstances. Implementers of the standard are responsible for determining appropriate safety, security, environmental, and health practices or regulatory requirements.

This IEEE document is made available for use subject to important notices and legal disclaimers. These notices and disclaimers appear in all publications containing this document and may be found under the heading “Important Notice” or “Important Notices and Disclaimers Concerning IEEE Documents.” They can also be obtained on request from IEEE or viewed at <http://standards.ieee.org/IPR/disclaimers.html>.

1 Overview

1.1 Scope

This standard provides definitions and explanations of key concepts in the fields of spectrum management, cognitive radio, policy-defined radio, adaptive radio, software-defined radio, and related technologies. The document goes beyond simple, short definitions by providing amplifying text that explains these terms in the context of the technologies that use them. The document also describes how these technologies interrelate and create new capabilities while at the same time providing mechanisms supportive of new spectrum management paradigms such as dynamic spectrum access.

1.2 Purpose

New concepts and technologies are rapidly emerging in the fields of spectrum management, policy-defined radio, adaptive radio, software-defined radio, reconfigurable radio, and networks and related technologies. Many of the terms used do not have precise definitions or have multiple definitions. This document facilitates the development of these technologies by clarifying the terminology and how these technologies relate to each other.

1.3 Flow of the document

Because of the complexity and interrelationship of some of the terms used in discussing advanced radio system technologies, additional tutorial material is provided in informative annexes and NOTES. It is the purpose of this additional tutorial material to amplify and clarify the briefer definitions. However, it is not the intent of this informative text to provide an exhaustive description of these technologies and new spectrum management concepts, but to provide high-level descriptive information to supplement the brief definitions.

Clause 2 of the document provides definitions of advanced radio system terms, whereas Clause 3 defines the functional capabilities associated with these systems. Clause 4 defines some network technologies that support the distributed functionality of these systems. Spectrum management terms and definitions are found in Clause 5. Ancillary terms are found in Clause 6. The annexes are non-normative (not part of the standard) but are included to provide additional information on the advanced radio system and spectrum management concepts that are the focus of this standard.

2 Definitions of advanced radio system concepts

For the purposes of this document, the following terms and definitions apply. *The Authoritative Dictionary of IEEE Standards Terms* [B7]¹ should be referenced for terms not defined in Clause 2 through Clause 6. Annex B provides information (non-normative text) that illustrates the relationship of terminology, including **reconfigurable radio**, **software-defined radio**, and **software-controlled radio**.

2.1 Adaptive radio

A type of **radio**² in which communications systems have a means of monitoring their own performance and a means of varying their own parameters by closed-loop action to improve their performance.

2.2 Cognitive radio^{3, 4}

a) A type of **radio** in which communication systems are aware of their environment and internal state and can make decisions about their radio operating behavior based on that information and predefined objectives.

NOTE—The environmental information may or may not include location information related to communication systems.⁵

b) Cognitive radio [as defined in item a)] that uses **software-defined radio**, **adaptive radio**, and other technologies to adjust automatically its behavior or operations to achieve desired objectives.

¹ The numbers in brackets correspond to those of the bibliography in Annex D.

² In this standard, words in the definition of a term are typed in bold font if they are defined elsewhere in the standard. For example, the word “**radio**” is typed in bold in the definition of “**cognitive radio**” because the term “**radio**” is defined elsewhere in this standard.

³ The IEEE recognizes that the terminology commonly used is “cognitive radio.” However, generally the cognitive functionality may be outside the boundary normally associated with a radio (e.g., environment sensing is a cognitive function that is not normally part of a radio).

⁴ The IEEE notes that the terms “dumb radio,” “aware radio,” and “smart radio” are used in the technical literature, but the IEEE does not define these terms at this time. They are additional descriptive terms that are sometimes applied to radios.

⁵ Notes in text, tables, and figures are given for information only and do not contain requirements needed to implement the standard.

2.3 Hardware-defined radio (see hardware radio)

2.4 Hardware radio

A type of **radio** that implements communications functions entirely through hardware such that changes in communications capabilities can only be achieved through hardware changes. *Contrast:* **software-defined radio**.

NOTE 1—Replacing a hardware component with an identical component containing different stored data or executable instructions is considered to be a physical modification of the device. Furthermore, a device having regulated parameters that can be changed without physical modification is not considered a hardware radio, even if such change requires specialized equipment or proprietary procedures.

NOTE 2—For consistency with regulatory definitions of **software-defined radio**, regulators often consider a hardware radio to be a type of **radio**, regardless of the communications function implementation technique, in which regulated emission or reception parameters cannot be changed in the field, post manufacture, without physically modifying the device.

NOTE 3—This term represents an idealized abstraction that is useful in designating categories of radio devices (e.g., **hardware radio**, **software-defined radio**, and **cognitive radio**) to which certain regulatory provisions or functional capabilities may apply. The term is also useful in describing the general evolution in the software reconfigurability of radio devices with **hardware radio** not being software reconfigurable and **software-defined radio** being software reconfigurable.

2.5 Intelligent radio

A type of **cognitive radio** that is capable of **machine learning**. *See also:* **machine learning**.

NOTE—Intelligent radio is considered a subset of **software-controlled radio**. This dependency occurs because the definition for **machine learning** in 6.3 requires an intelligent radio to adapt the decision-making process, which implies dynamic reprogramming. The reprogramming of radio control would not be possible unless the **radio** were also **software controlled**. However, such a **radio** need not be **software defined** since it would be possible for an intelligent radio to use software control to adapt the decision-making process controlling how or when a fixed set of hardware-defined physical layer implementations are used. A **software-defined, software-controlled** intelligent radio would have the additional ability to change the physical layer implementation dynamically under software control.

2.6 Policy-based radio

A type of **radio** in which the behavior of communications systems is governed by a policy-based control mechanism. *See also:* **policy-based control mechanism**.

NOTE 1—Policies may restrict behaviors (e.g., policies constraining time, power, or frequency use) associated with a specific set of radio functions, but they do not necessarily change the functional capability of a radio. Because policies often do not change basic radio functionality, a policy-based radio need not also be a reconfigurable radio.

NOTE 2—Because the definition for the term policy-based control mechanism in 3.6 considers radio policy to be a type of radio control software, the policy-based radio is considered a subset of **software-controlled radio**.

2.7 Reconfigurable radio

A type of **radio** whose functionality can be changed either through manual reconfiguration of radio modules or under software control.

NOTE 1—Software reconfiguration control of such radios may involve any element of the radio-communication network.

NOTE 2—Manual reconfiguration of the radio includes the physical change or removal of hardware components.

2.8 Software-controlled radio

A type of **radio** where some or all of the physical layer functions are *software controlled*.

2.9 Software-defined radio

A type of **radio** in which some or all of the physical layer functions are **software defined**. *Contrast: hardware radio.*

NOTE 1—Radios in which the communications functions are implemented in software are considered hardware radios for regulatory purposes if the regulated emission or reception parameters cannot be changed in the field, post manufacture, without physically modifying the device. However, a device having regulated parameters that can be changed without physical modification is considered a **software-defined radio**, even if such a change requires specialized equipment or proprietary procedures.

NOTE 2—This term represents an idealized abstraction that is useful in designating categories of radio devices (e.g., **hardware radio**, **software-defined radio**, and **cognitive radio**) to which certain regulatory provisions or functional capabilities may apply. The term is also useful in describing the general evolution in the software reconfigurability of radio devices with **hardware radio** not being software reconfigurable and **software-defined radio** being software reconfigurable. **Software-defined radios** include software reconfigurable hardware such as microprocessors, digital signal processors, and field programmable gate arrays that are used with software to implement communications functions. The degree of software reconfigurability will depend on the radio implementation.

NOTE 3—U.S. Federal Communications Commission Definition: A radio that includes a transmitter in which the operating parameters of frequency range, modulation type, or maximum output power (either radiated or conducted), or the circumstances under which the transmitter operates in accordance with Commission rules, can be altered by making a change in software without making any changes to hardware components that affect the radio frequency emissions (U.S. Federal Communications Commission FCC05-57 [B26]).

NOTE 4—ITU-R Definition (ITU-R M.2063 [B17] and ITU-R M.2064 [B18]) (including the text in the dashed list):

A radio in which RF operating parameters including but not limited to frequency range, modulation type, or output power can be set or altered by software, or the technique by which this is achieved.

- Excludes changes to operating parameters that occur during the normal preinstalled and predetermined operation of a radio according to a system specification or standard.
- SDR is an implementation technique applicable to many radio technologies and standards.
- Within the mobile service, SDR techniques are applicable to both transmitters and receivers.

NOTE 5—For the purposes of this standard, the term “SDR” may be applied to radios consisting of one or more transmitters, receivers, or combinations of both. It is noted that the FCC definition of SDR is applicable only to the transmitter portion of the radio. The ITU-R and IEEE definitions of software-defined radio are applicable to both the transmitter and the receiver.

3 Definitions of radio system functional capabilities

3.1 Adaptive modulation

A radio system function for adjusting the modulation format.

NOTE—Typically, these adjustments are in response to link and other external conditions and are used to achieve desired performance (e.g., bit error ratio, data rate, robustness, and range).

3.2 Cognitive control mechanism

A component of a **cognitive radio** that assesses inputs such as environmental, spectral, and communications channel conditions and predefined objectives to make decisions about radio operating behavior.

3.3 Frequency agility

The ability of a radio to change its operating frequency automatically; typically these changes are rapid or span a wide frequency range or have both of these change characteristics.

NOTE 1—The timing of frequency changes and the sequence of tuned frequencies may be preset or adaptive in response to changing conditions such as detected interference or jamming.

NOTE 2—Some applications of frequency agility include frequency hopping to reduce the effects of interference or jamming, frequency diversity transmission to reduce the effects of frequency-dependent multipath signal propagation, and dynamic spectrum access to operate on underutilized spectrum opportunistically or to operate on spectrum available through short-term agreements.

3.4 Geolocation capability

The ability to locate one's position in respect to the surface of the Earth.

NOTE—An adaptive radio having a **geolocation capability** may use awareness of its position as an input that influences its behavior. Accurate location awareness could improve the performance of dynamic spectrum access and support the implementation of radio-based policies having geographic constraints. Geolocation awareness may be in terms of absolute coordinates (e.g., GPS) or relative to other radios (e.g., multilateration using precise signal time of arrival measurements).

3.5 Location awareness

The ability of a **radio** to determine its location.

NOTE—Location may refer to geographical coordinates (longitude, latitude, and altitude) or to other information such as what country or city the radio is in.

3.6 Policy-based control mechanism

A mechanism that governs radio behavior by sets of rules, expressed in a machine-readable format, that are independent of the radio implementation regardless of whether the radio implementation is in hardware or software.

NOTE 1—The definition of rules and associated modification of radio functionality can occur:

- a) During manufacture or reconfiguration
- b) During configuration of a device by the user or service provider
- c) During over-the-air provisioning
- d) By over-the-air or other real-time control

NOTE 2—As implied by the scope of this standard, the control of radio dynamic spectrum access behavior is expected to be a typical application of a policy-based control mechanism. However, the concepts of policy-based control could be applied to network management policies as well. Policy sources include spectrum regulators, manufacturers, and network operators.