

IEEE Standard for Modeling Spectrum Consumption

IEEE Communications Society

Developed by the
IEEE Standard for Modeling Spectrum Consumption

IEEE Std 1900.5.2™-2024
(Revision of IEEE Std 1900.5.2-2017)

STANDARDS

IEEE Standard for Modeling Spectrum Consumption

Sponsor

Dynamic Spectrum Access Networks Standards Committee
of the
IEEE Communications Society

Approved 11 December 2024

IEEE SA Standards Board

Abstract: A vendor-independent generalized method for modeling spectrum consumption of any type of use of radio frequency spectrum and the attendant computations for arbitrating the compatibility among models are defined in this standard. The methods of modeling are chosen to support the development of tractable algorithms for determining the compatibility between models and for performing various spectrum management tasks that operate on a plurality of models. The modeling methods are exclusively focused on capturing spectrum use but are defined in a schema that can be joined with other schemata related to spectrum management.

Keywords: DSA, dynamic spectrum access, IEEE 1900.5.2™, SCM, spectrum consumption model

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

Copyright © 2025 by The Institute of Electrical and Electronics Engineers, Inc.
All rights reserved. Published 30 June 2025. Printed in the United States of America.

IEEE is a registered trademark in the U.S. Patent & Trademark Office, owned by The Institute of Electrical and Electronics Engineers, Incorporated.

PDF: ISBN 979-8-8557-2094-5 STD27850
Print: ISBN 979-8-8557-2095-2 STDPD27850

IEEE prohibits discrimination, harassment, and bullying.

For more information, visit <http://www.ieee.org/web/aboutus/whatis/policies/p9-26.html>.

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.

Important Notices and Disclaimers Concerning IEEE Standards Documents

IEEE Standards documents are made available for use subject to important notices and legal disclaimers. These notices and disclaimers, or a reference to this page (<https://standards.ieee.org/ipr/disclaimers.html>), appear in all IEEE standards and may be found under the heading “Important Notices and Disclaimers Concerning IEEE Standards Documents.”

Notice and Disclaimer of Liability Concerning the Use of IEEE Standards Documents

IEEE Standards documents are developed within IEEE Societies and subcommittees of IEEE Standards Association (IEEE SA) Board of Governors. IEEE develops its standards through an accredited consensus development process, which brings together volunteers representing varied viewpoints and interests to achieve the final product. IEEE standards are documents developed by volunteers with scientific, academic, and industry-based expertise in technical working groups. Volunteers involved in technical working groups are not necessarily members of IEEE or IEEE SA and participate without compensation from IEEE. While IEEE administers the process and establishes rules to promote fairness in the consensus development process, IEEE does not independently evaluate, test, or verify the accuracy of any of the information or the soundness of any judgments contained in its standards.

IEEE makes no warranties or representations concerning its standards, and expressly disclaims all warranties, express or implied, concerning all standards, including but not limited to the warranties of merchantability, fitness for a particular purpose and non-infringement. IEEE Standards documents do not guarantee safety, security, health, or environmental protection, or compliance with law, or guarantee against interference with or from other devices or networks. In addition, IEEE does not warrant or represent that the use of the material contained in its standards is free from patent infringement. IEEE Standards documents are supplied “AS IS” and “WITH ALL FAULTS.”

Use of an IEEE standard is wholly voluntary. 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.

In publishing and making its standards available, IEEE is not suggesting or rendering professional or other services for, or on behalf of, any person or entity, nor is IEEE undertaking to perform any duty owed by any other person or entity to another. Any person utilizing any IEEE Standards document should rely upon their own independent judgment in the exercise of reasonable care in any given circumstances or, as appropriate, seek the advice of a competent professional in determining the appropriateness of a given IEEE standard.

IN NO EVENT SHALL IEEE BE LIABLE FOR ANY DIRECT, INDIRECT, INCIDENTAL, SPECIAL, EXEMPLARY, OR CONSEQUENTIAL DAMAGES (INCLUDING, BUT NOT LIMITED TO: THE NEED TO PROCURE SUBSTITUTE GOODS OR SERVICES; LOSS OF USE, DATA, OR PROFITS; OR BUSINESS INTERRUPTION) HOWEVER CAUSED AND ON ANY THEORY OF LIABILITY, WHETHER IN CONTRACT, STRICT LIABILITY, OR TORT (INCLUDING NEGLIGENCE OR OTHERWISE) ARISING IN ANY WAY OUT OF THE PUBLICATION, USE OF, OR RELIANCE UPON ANY STANDARD, EVEN IF ADVISED OF THE POSSIBILITY OF SUCH DAMAGE AND REGARDLESS OF WHETHER SUCH DAMAGE WAS FORESEEABLE.

Translations

The IEEE consensus balloting process involves the review of documents in English only. In the event that an IEEE standard is translated, only the English language version published by IEEE is the approved IEEE standard.

Use by artificial intelligence systems

In no event shall material in any IEEE Standards documents be used for the purpose of creating, training, enhancing, developing, maintaining, or contributing to any artificial intelligence systems without the express, written consent of IEEE SA in advance. “Artificial intelligence” refers to any software, application, or other system that uses artificial intelligence, machine learning, or similar technologies, to analyze, train, process, or generate content. Requests for consent can be submitted using the Contact Us form.

Official statements

A statement, written or oral, that is not processed in accordance with the IEEE SA Standards Board Operations Manual is not, and shall not be considered or inferred to be, the official position of IEEE or any of its committees and shall not be considered to be, or be relied upon as, a formal position of IEEE or IEEE SA. At lectures, symposia, seminars, or educational courses, an individual presenting information on IEEE standards shall make it clear that the presenter’s views should be considered the personal views of that individual rather than the formal position of IEEE, IEEE SA, the Standards Committee, or the Working Group. Statements made by volunteers may not represent the formal position of their employer(s) or affiliation(s). News releases about IEEE standards issued by entities other than IEEE SA should be considered the view of the entity issuing the release rather than the formal position of IEEE or IEEE SA.

Comments on standards

Comments for revision of IEEE Standards documents are welcome from any interested party, regardless of membership affiliation with IEEE or IEEE SA. However, **IEEE does not provide interpretations, consulting information, or advice pertaining to IEEE Standards documents.**

Suggestions for changes in documents should be in the form of a proposed change of text, together with appropriate supporting comments. Since IEEE standards represent a consensus of concerned interests, it is important that any responses to comments and questions also receive the concurrence of a balance of interests. For this reason, IEEE and the members of its Societies and subcommittees of the IEEE SA Board of Governors are not able to provide an instant response to comments or questions, except in those cases where the matter has previously been addressed. For the same reason, IEEE does not respond to interpretation requests. Any person who would like to participate in evaluating comments or revisions to an IEEE standard is welcome to join the relevant IEEE SA working group. You can indicate interest in a working group using the Interests tab in the Manage Profile & Interests area of the [IEEE SA myProject system](#).¹ An IEEE Account is needed to access the application.

Comments on standards should be submitted using the [Contact Us](#) form.²

¹ Available at: <https://development.standards.ieee.org/myproject-web/public/view.html#landing>.

² Available at: <https://standards.ieee.org/about/contact/>.

Laws and regulations

Users of IEEE Standards documents should consult all applicable laws and regulations. Compliance with the provisions of any IEEE Standards document does not constitute 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.

Data privacy

Users of IEEE Standards documents should evaluate the standards for considerations of data privacy and data ownership in the context of assessing and using the standards in compliance with applicable laws and regulations.

Copyrights

IEEE draft and approved standards are copyrighted by IEEE under U.S. and international copyright laws. They are made available by IEEE and are adopted 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 these documents available for use and adoption by public authorities and private users, neither IEEE nor its licensors waive any rights in copyright to the documents.

Photocopies

Subject to payment of the appropriate licensing fees, IEEE will grant users a limited, non-exclusive license to photocopy portions of any individual standard for company or organizational internal use or individual, non-commercial use only. To arrange for payment of licensing fees, please contact Copyright Clearance Center, Customer Service, 222 Rosewood Drive, Danvers, MA 01923 USA; +1 978 750 8400; <https://www.copyright.com/>. Permission to photocopy portions of any individual standard for educational classroom use can also be obtained through the Copyright Clearance Center.

Updating of IEEE Standards documents

Users of IEEE Standards documents 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.

Every IEEE standard is subjected to review at least every 10 years. When a document is more than 10 years old and has not undergone a revision process, 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 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 [IEEE Xplore](#) or [contact IEEE](#).³ For more information about the IEEE SA or IEEE's standards development process, visit the IEEE SA Website.

Errata

Errata, if any, for all IEEE standards can be accessed on the [IEEE SA Website](#).⁴ Search for standard number and year of approval to access the web page of the published standard. Errata links are located under the Additional Resources Details section. Errata are also available in [IEEE Xplore](#). Users are encouraged to periodically check for errata.

Patents

IEEE standards are developed in compliance with the [IEEE SA Patent Policy](#).⁵

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 by the IEEE with respect to the existence or validity of any patent rights in connection therewith. If a patent holder or patent applicant has filed a statement of assurance via an Accepted Letter of Assurance, then the statement is listed on the IEEE SA Website at <https://standards.ieee.org/about/sasb/patcom/patents.html>. Letters of Assurance may indicate whether the Submitter is willing or unwilling to grant licenses under patent 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.

Essential Patent Claims may exist for which a Letter 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 provided in connection with submission of a Letter of Assurance, if any, or in any licensing agreements are reasonable or non-discriminatory. Users of this standard are expressly advised that determination of the validity of any patent rights, and the risk of infringement of such rights, is entirely their own responsibility. Further information may be obtained from the IEEE Standards Association.

IMPORTANT NOTICE

Technologies, application of technologies, and recommended procedures in various industries evolve over time. The IEEE standards development process allows participants to review developments in industries, technologies, and practices, and to determine what, if any, updates should be made to the IEEE standard. During this evolution, the technologies and recommendations in IEEE standards may be implemented in ways not foreseen during the standard's development. IEEE standards development activities consider research and information presented to the standards development group in developing any safety recommendations. Other information about safety practices, changes in technology or technology implementation, or impact by peripheral systems also may be pertinent to safety considerations during implementation of the standard. Implementers and users of IEEE Standards documents are responsible for determining and complying with all appropriate safety, security, environmental, health, data privacy, and interference protection practices and all applicable laws and regulations.

³ Available at: <https://ieeexplore.ieee.org/browse/standards/collection/ieee>.

⁴ Available at: <https://standards.ieee.org/standard/index.html>.

⁵ Available at: <https://standards.ieee.org/about/sasb/patcom/materials.html>.

Participants

At the time this standard was completed, the Policy Language and Architectures for Managing Cognitive Radio for Dynamic Spectrum Access Applications Working Group had the following membership:

John A. Stine, *Chair*
Carlos E. Caicedo-Bastidas, *Vice Chair*
Eric Lindahl, *Secretary*
John Stine, *Editor*

Julia Andrusenko
Shastri Jayram
Brent Josefiak

Alexander Lackpour
Ahmed “Mohin” Mohuiddin
Tony Rennie

Becca Rousseau
Reinhard Schrage
Kael Stilp

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

Boon Chong Ang
Butch Anton
Harry Bims
Vern Brethour
Carlos E. Caicedo-Bastidas
Paul Cardinal
Pin Chang
Marc Emmelmann
P. Flynn
Edward Hare
Marco Hernandez
Werner Hoelzl
Oliver Holland
Shastri Jayram

Pranav Jha
Piotr Karocki
Stuart Kerry
Yongbum Kim
Shoichi Kitazawa
Hyeong Ho Lee
James Lepp
Eric Lindahl
Edward McCall
Yukimasa Nagai
Dries Neirynck
Bansi Patel
Arumugam Paventhan
Venkatesha Prasad

Maximilian Riegel
Reinhard Schrage
Dorothy Stanley
Thomas Starai
John Stine
Walter Struppler
Mark Sturza
Bo Sun
John Vergis
Scott Willy
Ludwig Winkel
Andreas Wolf
Oren Yuen
George Zimmerman

When the IEEE-SA Standards Board approved this standard on 11 December 2024, it had the following membership:

David J. Law, *Chair*
Jon Walter Rosdahl, *Vice Chair*
Gary Hoffman, *Past Chair*
Alpesh Shah, *Secretary*

Sara R. Biyabani
Ted Burse
Stephen Dukes
Doug Edwards
J. Travis Griffith
Guido R. Hiertz
Ronald W. Hotchkiss

Hao Hu
Yousef Kimiagar
Joseph L. Koepfinger*
Howard Li
Xiaohui Liu
John Haiying Lu
Kevin W. Lu
Hiroshi Mano

Paul Nikolich
Robby Robson
Lei Wang
F. Keith Waters
Sha Wei
Philip B. Winston
Don Wright

*Member Emeritus

Introduction

This introduction is not part of IEEE Std 1900.5.2-2024, IEEE Standard for Modeling Spectrum Consumption.

This document is a complete standard to define a generalized method for modeling spectrum consumption of any type of use of radio frequency spectrum and the attendant computations for arbitrating the compatibility among models. The methods of modeling are chosen to support the development of tractable algorithms for determining the compatibility between models and for performing various spectrum management tasks that operate on a plurality of models. The modeling methods are exclusively focused on capturing spectrum use to support the determination of compatibility as opposed to being a data standard that seeks to support a particular business process of spectrum management. This standard defines the data requirement for spectrum consumption models. The data elements and their meaning are the critical parts of the modeling and may be expressed by any data schema if content and context are preserved. However, this standard does provide two schemas, XML and JSON, for those seeking a normative schema for their use.

Contents

1. Overview	12
1.1 Scope	12
1.2 Purpose	12
1.3 Word usage	13
2. Normative references	13
3. Definitions, acronyms, and abbreviations	13
3.1 Definitions	13
3.2 Acronyms and abbreviations	15
3.3 Symbols	16
3.4 Constants	20
4. Data conventions	21
5. Purpose and use of SCMs	21
5.1 General	21
5.2 Capturing spectrum use of RF devices	22
5.3 Capturing spectrum use of RF systems	22
5.4 Model-based spectrum management (MBSM)	22
5.5 Radio spectrum use policy	25
6. Spectrum-dependent devices, systems, and sets	25
6.1 General	25
6.2 Spectrum-dependent devices	26
6.3 System models	26
6.4 SCM sets	27
6.5 SCM messages	28
6.6 SCM data hierarchy	28
7. Special data structures	29
7.1 General	29
7.2 Specifying confidence	29
7.3 Specifying values by direction	32
7.4 Spectral masks	33
8. Modeling constructs	34
8.1 General	34
8.2 Reference power	35
8.3 Spectrum mask	36
8.4 Underlay mask	41
8.5 Power map	49
8.6 Propagation map	58
8.7 Intermodulation (IM) mask	67
8.8 Platform	70
8.9 Location	71
8.10 Schedule	78
8.11 Minimum PSFD	80
8.12 Policy or protocol	80
9. Modeling requirements	83

9.1 Transmitters	83
9.2 Receivers	85
9.3 Transmitter configuration option	87
9.4 Receiver configuration options	89
9.5 Systems	91
9.6 Sets	100
10. Method used to compute compatibility	104
10.1 General	104
10.2 Time overlap	105
10.3 Common SystemID	105
10.4 Spectrum overlap	105
10.5 Link budget computations using models	105
10.6 Power margin between a spectrum mask and an underlay mask	113
10.7 Assessing effects of IntermodulationMask and platform constructs	123
10.8 Meeting policy or protocol criteria	128
10.9 Canonical locations	128
10.10 Selecting a coordinate reference for competing models	132
10.11 Constraining points	135
10.12 Least constraining points	137
10.13 Assessing aggregate effects	138
10.14 Interference from surfaces and volumes with multiple transmitters	142
11. Assessing compatibility	143
11.1 General	143
11.2 Model precedence	144
11.3 Assessment process	144
11.4 Using Confidence	148
12. Extended algorithms	153
12.1 Modifying models to achieve compatible reuse	153
12.2 Spectrum negotiation	154
12.3 Visualizing spectrum availability or use in space	154
12.4 Measuring spectrum consumption	154
13. Verification rules	155
13.1 General	155
13.2 Rules	155
14. XML schema	173
14.1 Conventions	173
14.2 Schema	173
15. JSON schema	199
15.1 Conventions	199
15.2 Schema	200
Annex A (informative) Bibliography	228
Annex B (informative) The World Geodetic System of 1984 (WGS 84) ellipsoid datum	230
Annex C (informative) Rotation matrices	233
C.1 General	233
C.2 Coordinate rotations	233
C.3 Directional computations	235

Annex D (informative) Coordinate conversions.....	237
Annex E (informative) Location modeling exemplars	239
E.1 General	239
E.2 Converting non-convex areas of operation to convex areas.....	239
E.3 Subdividing the area of operations based on time.....	240
E.4 Subdividing the area of operation based on propagation conditions	242
E.5 Differentiating antenna pointing based on time	244
E.6 Using location indexing to increase time and space resolution of a path	246
E.7 Combinatorial assessments of multiple location-associated constructs	246
E.8 Representing uncertainty in location and the constructs associated to each other through the LocationIndex.....	247
Annex F (informative) Computation exemplars.....	249
F.1 Modeling	249
F.2 Canonical locations	256
F.3 Compatibility assessment	268
F.4 Using confidence.....	295
Annex G (informative) Modeling and spectrum management activities.....	297
G.1 Goals.....	297
G.2 Gathering data.....	297
G.3 Specifying spectrum resources	297
G.4 Creating operational alternatives	298
G.5 Selecting options and decision support.....	298
G.6 Modeling decisions	299
G.7 Communicating decisions.....	299
G.8 Policy and DSA management	300
Annex H (informative) Capturing configuration options and requests.....	301
H.1 General.....	301
H.2 Tunable frequency transceiver.....	301
H.3 Tunable power transceiver.....	304
H.4 Multi-bandwidth transceiver.....	304
H.5 Frequency hopping transceiver.....	304
H.6 Directional transceiver.....	305
H.7 Multiple operational alternatives in a request	308
H.8 Modeling frequency tuning options for frequency division duplexing, repeaters, and transponders	308
Annex I (informative) Using rules and schemas	314
I.1 Example report of a schema validation errors.....	314

IEEE Standard for Modeling Spectrum Consumption

1. Overview

1.1 Scope

This standard defines a generalized method for modeling spectrum consumption of any type of use of radio frequency (RF) spectrum and the attendant computations for arbitrating the compatibility among models. The methods of modeling are chosen to support the development of tractable algorithms for determining the compatibility between models and for performing various spectrum management tasks that operate on a plurality of models. The modeling methods are exclusively focused on capturing spectrum use to support the determination of compatibility as opposed to being a data standard that seeks to support a particular business process of spectrum management. However, such externally defined spectrum management data standards can beneficially leverage the spectrum consumption modeling defined in this standard.

This standard defines the data requirement for spectrum consumption models (SCMs), provides data rules that help ensure an SCM is valid, and provides two schemas, one in JSON and another one in XML Schema Definition (XSD), to support SCM data exchange. The data elements and their meaning are the critical parts of the modeling and may be expressed by any data schema if content and context are preserved.

1.2 Purpose

This standard defines an analytical framework of necessary modeling constructs that can be used to express the boundaries of spectrum consumption by any transmitting or receiving device. These constructs can be combined into a machine-readable data exchange schema for the purpose of transferring these SCMs between automated systems. This standard can serve as a loose coupler for the spectrum management enterprise by providing all spectrum communities of interest with a common way to express spectrum consumption. Further, the standard describes algorithms that can evaluate compatibility among SCMs and enables the creation of algorithms that can perform spectrum management tasks such as finding reuse opportunities or optimizing spectrum assignments to increase spectrum utilization. To achieve this goal, the SCMs must be sufficient in that the algorithms can perform these functions using the models alone without dependence on external information.

The effectiveness of these approaches depends on the quality of the models. The quality of the models depends on the quality of the data on system performance used to build the models and the willingness of the modelers to reveal the true use and vulnerability of the systems to interference. Specifying the required data quality and the accuracy of the models is beyond the scope of the standard.

1.3 Word usage

The word *shall* indicates mandatory requirements strictly to be followed in order to conform to the standard and from which no deviation is permitted (*shall* equals *is required to*).^{6,7}

The word *should* indicates that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others; or that a certain course of action is preferred but not necessarily required (*should* equals *is recommended that*).

The word *may* is used to indicate a course of action permissible within the limits of the standard (*may* equals *is permitted to*).

The word *can* is used for statements of possibility and capability, whether material, physical, or causal (*can* equals *is able to*).

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

There are no normative references in this standard.

3. Definitions, acronyms, and abbreviations

3.1 Definitions

For the purposes of this document, the following terms and definitions apply. IEEE Std 1900.1™ [B3] should be consulted for terms not defined in this clause.⁸

canonical receiver model: A spectrum consumption model of a receiver that stands alone as a model and does not use location indices.

canonical transmitter model: A spectrum consumption model of a transmitter that stands alone as a model and does not use location indices.

compatible spectrum consumption models (SCMs): Two or more spectrum consumption models where none of the receiver models in those SCMs receive incompatible interference from the aggregate of the transmitter models in those SCMs.

incompatible interference: Interference that exceeds the threshold interference limits defined for a receiver model used in model-based spectrum management.

link budget scaled mask: A spectrum mask that has been scaled to account for all sources of attenuation up to the input to a receiver antenna.

⁶ The use of the word *must* is deprecated and cannot be used when stating mandatory requirements; *must* is used only to describe unavoidable situations.

⁷ The use of *will* is deprecated and cannot be used when stating mandatory requirements; *will* is only used in statements of fact.

⁸ The numbers in brackets correspond to the numbers of the bibliography in Annex A.

local regulating administration: The administration with legal authority to establish policy for the use of spectrum within the local geographic region.

model-based spectrum management (MBSM): Spectrum management based on the creation, exchange, and analysis of spectrum consumption models (SCMs).

NOTE—Incumbent and proposed spectrum uses are captured in SCMs. The efficacy of proposed uses is arbitrated based on the compatibility of these models.⁹

modeler: An entity, person, or machine that builds a model of spectrum use.

receiver model: A spectrum consumption model that defines the threshold boundaries for incompatible interference for a receiving device.

spectrum authorization set: A set of spectrum consumption models (SCMs) that define spectrum that is available for a system to use where an allowed use of spectrum is one that falls within the limits of one or more of the SCMs in this set.

spectrum boundary: The spatial, spectral, and temporal extent of relevance of the spectrum consumption models in a consumption authorization or constraint set.

spectrum constraint set: A set of spectrum consumption models with which a new use must not cause incompatible interference and must accept interference. Spectrum constraint sets are given together with a spectrum authorization set to define spectrum availability.

spectrum consumption model (SCM): A model of spectrum use identifying the key phenomenology and operational use that can be used to determine the extent of radio frequency spectrum effects that preclude others from using it.

NOTE—Use of the SCMs presumes a set of agreed methods for evaluating compatibility between models in support of model-based spectrum management.

spectrum consumption set: A spectrum boundary and set of spectrum consumption models that impact uses of spectrum within that boundary.

spectrum management enterprise: An organization that needs to arbitrate the use of spectrum by its own spectrum-dependent systems and therefore warrants its own spectrum management activity.

spectrum manager: An organization, person, or automated process that arbitrates the access to spectrum.

system manager: A person or automated process that manages the collective set of devices of a system and their use of resources, including the radio frequency spectrum that they use, for example, a wireless network manager.

system model: A spectrum consumption model with a set of transmitter and receiver models that collectively capture the spectrum use of a spectrum-dependent system.

transmitter model: A spectrum consumption model that bounds the radio frequency emissions of a transmitting device.

⁹ Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement this standard.

3.2 Acronyms and abbreviations

AGL	above ground level
DSA	dynamic spectrum access
EQ	equal
FDR	frequency dependent rejection
GT	greater than
GTE	greater than or equal
HAAT	height above average terrain
IF	intermediate frequency
IM	intermodulation
IMA	intermodulation amplification
IMC	intermodulation combining
LT	less than
LTE	less than or equal
MBSM	model-based spectrum management
NEQ	not equal
PFD	power flux density
PSD	power spectral density
PSFD	power spectral flux density
RBW	resolution bandwidth
RF	radio frequency
SCM	spectrum consumption model
SDD	spectrum-dependent device
SLA	service-level agreement
TIREM	Terrain Integrated Rough Earth Model
UAV	unmanned aerial vehicle
UTC	Coordinated Universal Time
WGS 84	World Geodetic System of 1984

3.3 Symbols

Symbol	Description	Where used
ϕ	Elevation in a map	7.3
θ	Azimuth in a map	7.3
λ	Longitude	8.9, Annex B
λ	Wavelength	Annex F
λ_r	Wavelength dependent receiver antenna aperture loss	10.5.3
Γ	Reflection coefficient	Annex F
φ	Latitude	8.9, Annex B
φ	Yaw	Annex C
θ	Pitch	Annex C
ψ	Roll	Annex C
α	Angle of rotation about the z axis	8.5.2.3, Annex C
β	Angle of rotation about the y axis	8.5.2.3, Annex C
γ	Angle of rotation about the x axis	8.5.2.3, Annex C
μ	Magnetic permeability of free space, 1.26×10^{-6} H/m	Annex F
ε	Electric permittivity of free space, 8.85×10^{-12} F/m	Annex F
σ	Conductivity	Annex F
Σ	Sum of heights	Annex F
Δ	Difference of heights	Annex F
ε_r	Relative dielectric constant	Annex F
a	Altitude	8.9, Annex B
a	Semi-minor ellipsoid axis	8.9, Annex B
a	Altitude	8.9.2.2, 10.9.4.3
A	Area	10.9.4.3
A	Set of fleeting constructs	11.4
ah	Antenna height	8.9
$arip$	Aggregate relative interference power	10.13.2.2
aip	Accumulated interference power	10.13.2.3
$AP_{mismatch}$	Antenna polarization mismatch loss between the transmitter polarization and receiver polarization	10.5.1
b	Semi-minor ellipsoid axis	8.9, Annex B
b	Coefficient of a linear equation representing a side of a spectrum mask	10.6, Annex F
b_0	Constant of a linear expression of side of a spectrum or underlay mask	10.6.2.2
b_l	Slope of a linear expression of a side of a spectrum or underlay mask	10.6.2.2
B	Set of fleeting constructs	11.4
bp	Breakpoint	8.6
b_R	Attenuation at the boundary of a receiver location	10.5.2
bl	Band below the receiver tuning frequency that a transmitter may be tuned that would result in interference	10.6.2.6.3
b_R	Attenuation at the boundary of a receiver location	10.5.2
B_r	Attenuation at the boundary of a receiver location	10.5.1
b_T	Attenuation at the boundary of a transmitter location	10.5.2
B_t	Attenuation at the boundary of a transmitter location	10.5.1
bu	Band above the receiver tuning frequency that a transmitter may be tuned that would result in interference	10.6.2.6.3
BW	Bandwidth	8.4, 10.6
bwm	Bandwidth overlap of a frequency band with an underlay mask	10.6.2.6
bwr	Combined bandwidth of all bands used in hopping at a receiver	10.6.2.6.3
bwt	Combined bandwidth of all bands used in hopping at a transmitter	10.6.2.6
c	Confidence	—
c	Speed of light, 3.00×10^8 m/s	—
CL	Left-hand circular polarization	8.5
CR	Right-hand circular polarization	8.5
d	Distance	8.6
d	Down coordinate direction	10.10.3, Annex D

Symbol	Description	Where used
d_a	Distance to the nearest point in a location intersecting a gain and pathloss model sector	10.14
d_b	Distance to the furthest point in a location intersecting a gain and pathloss model sector	10.14
$d_{breakpoint}$	Distance to a breakpoint	8.6
DC	Duty cycle	8.4
DD	Day	8.10
DT	Dwell time	8.4
dta	Dwell time accumulated	10.13.2.3
e	Eccentricity	Annex B
e	East coordinate direction	10.10.3, Annex D
E	Elliptical polarization	8.5
EL	Left elliptic polarization	8.5
ER	Right elliptic polarization	8.5
$\mathcal{E}$	Voltage intensity	Annex F
f	Frequency	8.3, 8.4, 8.7, 10.5, 10.6, 10.7, Annex F
f	Flattening	Annex B
f_{ref}	Reference frequency	8.4.1
F	45-degree polarization	8.5
f_c	Center frequency	7.4
f_c	Quantity of frequencies within the bandwidth of a mask	10.6.2.6
f_{ct}	Quantity of frequencies a radio uses in hopping	10.6.2.6
FDR	Frequency dependent rejection between a transmitter's spectrum mask and a receiver's underlay mask	10.5.1
f_{IF}	Intermediate frequency of a heterodyne receiver	10.7.2.3
f_{image}	Center frequency of an image of a heterodyne receiver underlay mask	10.7.2.3
f_{LO}	Local oscillator frequency of a heterodyne receiver	10.7.2.3
g	Gain density in a direction from a power map of the device at 1 m	10.5.2, 10.5.3
G	Cartesian coordinates of the centroid of a polygon	10.10.4.2
g_r	Gain of a receiver antenna	8.5.2.2
g_r	Gain from the power map of the local receiver	10.5
G_r	Gain from a receiver model power map	10.5.1
g_t	Gain of a transmitter antenna	8.5.2.2
g_t	Gain from the power map of a distant transmitter	10.5
G_t	Gain from a transmitter model power map	10.5.1
H	Horizontal polarization	8.5
HD	The hop density used for receiver hops in the numerical approximations when receiver hopping frequencies are specified using band lists	10.6.2.6.3
hh	Hours	8.10
HV	Horizontal and vertical polarization	8.5
i	Iterator	7.3, 11.4
IN_{Th}	Alternative interference threshold	9.4
I_{Th}	Interference threshold	9.4
j	Iterator	7.3, 11.4
l	Attenuation or pathloss across a side of a location	8.9
l	Rate of pathloss as a function of distance	8.6, 10.5
L	Linear polarization	8.5
l_B	Attenuation or pathloss across the base of a cylinder or a polyhedron	8.9
$LDL(d)$	Log-distance pathloss at distance d	8.6, 10.5
$LL(d)$	Linear-distance pathloss at distance d	8.6, 10.5
l_r	Insertion losses at a receiver antenna	8.5.2.2
l_t	Insertion losses at a transmitter antenna	8.5.2.2
mm	Minutes	8.10
MM	Month	8.10
n	Exponent for distance based pathloss	8.6
n	North coordinate direction	10.10.3, Annex D

Symbol	Description	Where used
nD	Number of days	8.10
nH	Number of hours	8.10
nM	Number of months or number of minutes based on order of appearance	8.10
nS	Number of seconds	8.10
NS	Number of signals within the overlap of a band list and an underlay mask to approximate the effect of hopping across that overlap	10.6.2.6.1
nY	Number of years	8.10
O	Oblique angle crossed polarization	8.5
OL	Oblique angled left polarization	8.5
OR	Oblique angled right polarization	8.5
P_{dBW}	Power (dBW)	4
P_W	Power (watts)	4
p	Represents a generic model parameter in a map data structure	7.3
p	Relative power (dB)	8.3, 8.4, 10.6, 10.7, Annex F
p	Probability	11.4
p	Power threshold	10.13.2.2
$\mathcal{P}$	Power flux density	Annex F
p_{acc}	Accumulated power from a density of transmitters in a location at the intersection of a gain–propagation model sector	10.14
p_{adj}	Power adjustment	9.4
$p_{aggregate_interference}$	Aggregate interference from multiple interfering transmitters at a receiver	10.6.2.2
$p_{allowed_interference}$	Interference power allowed by an underlay mask	10.6.2.2
$p_{avg_interference}$	Average power of interference from a frequency hopping signal at a single channel receiver	10.6.2.6.1
$pdif$	Power differentiation	10.13.2.3
pfd	Power flux density	8.5.2.2
$p_{interference}$	Interference power at a receiver	10.6.2.2
p_{int}	Integrated power	10.14
pl	Pathloss	10.5.2, 10.5.3
PL	A computed pathloss	10.5
pl_a	Pathloss computed to the nearest point in a location intersecting a gain and pathloss model sector	10.14
pl_b	Pathloss computed to the furthest point in a location intersecting a gain and pathloss model sector	10.14
PL_r	Pathloss computed using a receiver model	10.5
PL_t	Pathloss computed using a transmitter model	10.5
$PL(d)$	Pathloss predicted by a propagation model at a distance d	10.5.1
pm	Minimum power value in an underlay mask	10.6.2
PM_{masks}	Power margin between masks	10.5.1, 10.6.2.2
p_r	Probability that a receiver is operating at a frequency indexed by r and there is interference at that hop from a hopping transmitter	10.6.2.6.3
ps	Power term from a spectrum mask	10.6
ps	Polygon sides	8.9.2.2.4
p_{scl}	Scaled power per meter of distance to get average power	10.14
p_t	Power driving a transmitter antenna	8.5.2.2, 10.14
p_t	Probability that a transmitter is operating at a frequency indexed by t and it causes interference to a hopping receiver	10.6.2.6.3
P_t	Transmitter reference power	10.5.1
q	Number	7.2
q_r	Probability of interference at a hopping receiver when operating at a hop frequency indexed by r	10.6.2.6.3
q_t	Probability that a transmitter will interfere with a hopping receiver when operating at the frequency indexed by t	10.6.2.6.3
R	Three-dimensional space of the location of a receiver	10.11, 10.12
R	Rotating polarization	8.5
R	Quantity of frequencies in a frequency list at a receiver	10.6.2.6.3
r^*	Potential receiver location	10.12
RBW	Resolution bandwidth	8.3, Annex F

Symbol	Description	Where used
rip	Relative interference power	10.13.2.2
rp	Reference power	10.5.2
rp	Revisit period	10.13.2.3
$RP(1m)$	Received power at 1 m distance from an antenna	8.6
$RP(d)$	Received power at distance d	8.6
rrp	Reference revisit period	10.13.2.3
ρT	Transmitter density	8.9.2.2.3, 8.9.2.2.4, Annex F
s	A signal in a signal set S	10.6
S	Expected minimum strength of a signal	9.4
S	A signal set	10.6
S	A signal name	10.7
sa	Starting azimuth	8.9.2.2.4
sd	Segmentation distance	8.9.2.2
SS	Quantity of signal samples used across a receiver's set of band lists in computing the probability of interference	10.6.2.6.3
$ss.s$	Seconds	8.10
t	Time	8.9
T	Three-dimensional space of the location of a transmitter	10.11
T	Quantity of frequencies in a frequency list at a transmitter	10.6.2.6.3
ta	Fraction of time a transmitter is active	10.6
TC	Right- and left-hand circular polarization	8.5
td	Dwell time	10.6.2.6
th	Hope period	10.6.2.6
U_{3dB}	Power under the 3 dB bandwidth of an underlay mask	10.5.1
v	Radius of curvature	Annex B
v	Vertex in Cartesian coordinates	10.10.4.2
vh	Height in circle or polygon to indicate a cylinder or polyhedron	8.9.2.2
V	Vertical polarization	8.5
w	Expected quantity of transmitters at a location with a density of transmitter within the intersection of a gain-pathloss model sector	10.14
w_r	Quantity of transmitter hops that would interfere with a hopping receiver operating at a frequency indexed by r when the hopping transmitter has a frequency list or the bandwidth within the band lists of a frequency hopping transmitter where hops would interfere with a receiver operating at a frequency indexed by r	10.6.2.6.3
w_t	Bandwidth within the band lists of a hopping receiver where a receiver hop would receive interference from a transmitter operating at a frequency indexed by t	10.6.2.6.3
x	Coordinate direction	8.9
x_R	X coordinate of a receiver	10.11
x_T	X coordinate of a transmitter	10.11
y	Coordinate direction	8.9
y_R	Y coordinate of a receiver	10.11
y_T	Y coordinate of a transmitter	10.11
$YYYY$	Year	8.10
z	Coordinate direction	8.9
z_R	Z coordinate of a receiver	10.11
z_T	Z coordinate of a transmitter	10.11

3.4 Constants

This standard provides common computational methods for the arbitration of compatibility. Several of the compatibility equations involve parameters that are choices. The convention for the following constants is that they are the choice used unless overridden by inputs into the data structures of models.

Constants	Description	Default value	Where used
HOP_DENSITY	The hop density used for receiver hops in the numerical approximations when receiver hopping frequencies are specified using band lists.	10	8.4.2, 10.6.2.6.3
SIGNAL_QUANTITY	Quantity of signals within the overlap of a band list and an underlay mask to approximate the average power of hopping across that overlap.	9	8.4.2, 10.6.2.6.1
MAX_SEGMENTATION_DISTANCE	The maximum separation between adjacent points of subsequent triangulations in meters of a large polygon surface and between the points on the base of a large polyhedron base and in the segmentation of long paths and surface path segments.	100 000	8.9.2.1, 10.9.3
MIN_SEPARATION_DISTANCE	The minimum distance in meters to use in computing the pathloss between two co-located spectrum-dependent device (SDDs), for example, their locations overlap.	1	8.9.2.1, 10.11.2
CIRCLE_TO_POLYGON_SIDES	The quantity of equilateral sides used to approximate a circle so that all computations are based on polygons.	6	Table 22

4. Data conventions

The following table shows the formats and units of measure used within this document:

Type	Unit	Description
Power	dBW	Decibel watt. All power fields are recorded in units of decibel watt (dBW) in accordance with ITU treaty procedures, with power in decibel watt (dBW) calculated as follows: $P_{dBW} = 10 \log_{10} P_W$ where P_{dBW} = power in dBW P_W = power in watts
Relative power	dB	Decibel. Relative power levels are recorded in decibels (dB). Relative powers are recorded as a ratio of the two powers in units of dB, with the ratio calculated as follows: Power of P_1 relative to $P_2 = 10 \log_{10} (P_1/P_2)$, where P_1 and P_2 are the individual power quantities expressed in the same (linear-scale) units.
Gain	dB	A gain indicates amplification. When the word <i>gain</i> is used with a value, that value is added in a link budget equation. A gain value may be positive or negative. When gains are negative, they are actually losses indicating attenuation
Loss	dB	A loss indicates attenuation. When the word <i>loss</i> is used with a value, that value is subtracted in the link budget equation. A loss value may be positive or negative. When losses are negative, they are actually gains indicating amplification.
Power spectral flux density (PSFD)	dBW/Hz/m ²	PSFD is recorded as a decimal number with units of decibel watt per hertz per square meter (dBW/Hz/m ²).
Frequency	MHz	Megahertz. Frequency is noted in MHz. This specification follows common practice and ITU convention in which a frequency value is normally formatted with between zero to five decimal places. However, fractional Hz values are permitted, and a model may employ as many significant digits as required.
Geodetic datum	N/A	All geolocation references are measured and communicated using the World Geodetic System of 1984 (WGS 84) geodetic datum [B12].
Time	s	Second. All time values are recorded in seconds. Fractional seconds are permitted, and a model may employ however many significant digits are required. For example, one microsecond is noted as 0.000001 s or 0.0000010 s.
Distance	m	Meter. All distance values are recorded in meters unless otherwise explicitly declared. Fractional meters are permitted, and a model may employ as many significant digits as required.
Time zone	N/A	All date and time values are recorded in Coordinated Universal Time (the UTC time zone). The UTC time zone does not change with the change of seasons and does not observe daylight saving time.

5. Purpose and use of SCMs

5.1 General

The purpose of spectrum consumption models (SCMs) is to convey the extent of the use of spectrum in time, frequency and space, and to reveal what constitutes acceptable reuse. SCMs provide an unambiguous definition of the extent to which a system emits radiation and what the SCM's author would consider harmful interference to that system's operation. These models capture specific uses of spectrum as opposed

to being general characteristics of systems. They provide a means to capture and use the judgment of operational planners, RF system users, and spectrum managers.

SCMs provide a means to capture the spectrum consumption of RF devices and RF systems and to arbitrate the compatibility among them. A transmitter model is compatible with a receiver model if the emissions predicted from a transmitter model do not cross the interference thresholds of the receiver model. SCMs are self-contained meaning they do not require users to share any external database of environmental data and effects or of device performance data. Sharing SCMs is sufficient for arbitrating compatibility. These features and basic functionality enable distributed and dynamic spectrum management that can lead to better reuse of spectrum. Further, the models, when properly represented in a data exchange format, can serve as a means to specify in a machine-readable format the availability of spectrum for RF systems to self-select the RF spectrum they use.

5.2 Capturing spectrum use of RF devices

Both transmitters and receivers consume spectrum. Spectrum is consumed by an RF device to the extent that its transmitter precludes the receivers of another RF device from operating and to the extent that its receiver's protection requirements preclude the transmitters of other RF devices from operating. The spatial extent of consumption is determined by identifying the boundary of compatibility beyond which the secondary must operate. SCMs support the definition of these boundaries. Transmitter models define the extent of RF emissions. Receiver models define what constitutes interference. The computational methods for arbitrating compatibility between transmitters and receivers of different RF devices enable the determination of the separation boundary between those RF devices.

5.3 Capturing spectrum use of RF systems

RF systems generally consist of two or more RF devices that work collaboratively to perform a function. That function is dependent on all devices receiving some level of protection from interfering radiation from external RF devices and systems. SCMs can model the collective use of spectrum by multiple RF devices. These models consist of multiple transmitter and receiver models and/or of transmitter and receiver models that apply to spaces. A system is compatible with an external RF device or RF system if all models are compatible across all spaces in which they jointly apply. The same methods used for arbitrating compatibility among devices are used for arbitrating compatibility with systems. The lone difference is that multiple transmitter and receiver model pairs and the aggregate effects of multiple transmitters on a single receiver model may need to be evaluated for that determination.

5.4 Model-based spectrum management (MBSM)

5.4.1 General

MBSM is spectrum management based on the creation and exchange of SCMs. These SCMs can be used for all types of spectrum management activities.

- In regulation, SCMs can be used to define a user's spectrum usage rights.
- In operations, SCMs can enable dynamic and flexible management of spectrum resources thus increasing spectrum reuse. Peer spectrum managers and users can collaborate by sharing the models of their spectrum use.
- In technology, SCMs can be used to convey spectrum assignments and spectrum policy to RF systems.
- In commerce, SCMs are a means to capture the quanta of spectrum that are traded.

SCMs serve as a loose coupler for spectrum management. They allow the spectrum management problem to be distributed where users of spectrum can model their own use and then have their models used across the spectrum management enterprise to affect where and when new uses of the same spectrum may occur. Models support this determination because they stand alone from any database of environmental or system data and have well-defined attendant methods for arbitrating pairwise compatibility. These methods use the information in the models only.

5.4.2 Loose coupling spectrum management

A loose coupler is a data exchange specification based on the simple, useful, rough intersection of data sharing needs among many systems or an interface specification for interoperability among many systems. When identified and placed between the layers of complex systems, not only does it engender interoperability, but it also enables the larger system to support innovation. To be effective, the loose coupler must be well defined and broadly adopted. A couple of well-known systems serve as examples. The first is the electrical power system. The loose coupler is the specification for power distribution at the user end, frequency, voltage, and interface definition. This standardized coupler then allows innovation at two ends, power generation and electrical appliances and devices. There is no constraint to development of means of generating power so long as it can be converted into the frequency and voltage necessary at the end of the distribution. There is no constraint to the development of appliances and devices so long as they can accept power at the specified voltage and frequency. The second example is the Internet. The Internet Protocol (IP) serves as a loose coupler with the two layers being between the means of data transmission and the services of the internet. There can be innovation in the means to enable transport so long as the systems can accept and route IP packets and there can be innovation in the services and applications that ride the network and use the transport so long as they conform their communications to the standards of IP. The loose coupler in these systems is standardized.

Figure 1 illustrates the layering of the anticipated spectrum management system that uses SCMs as its loose coupler. The methods of modeling defined in this standard describe how to specify the boundaries of spectrum use and given a pair of SCMs, how to determine if they are compatible with each other. The SCMs are the loose coupler and are placed at the center of what is referred to as a bowtie diagram. The SCM definition allows disparate spectrum management systems and RF devices to coexist and to collaborate in the activities of spectrum management. Figure 1 illustrates the anticipated interactions. At the top layer it provides a means for systems that collectively perform spectrum management to convey¹⁰ to each other their vision of spectrum consumption. Thus, a heterogeneous collection of spectrum management systems can interoperate so long as they can articulate spectral quanta in SCMs. Organizations with spectrum management processes that are unique to themselves can create their own tools for management and then convey to peer managers of other organizations their spectrum use and their spectrum requirements using SCMs. At the bottom layer it allows RF systems that use the spectrum to coexist. RF devices adapt their use of spectrum to fit within the boundaries of a model or to stay away from the boundaries of other users whose models they are given. In the long term, multiple RF systems could autonomously collaborate to share spectrum and use SCMs to arbitrate and manage their spectrum sharing. Moving from layer to layer, SCMs provide a means for spectrum management systems to convey to RF systems what spectrum they can use and the conditions for its use. Finally, SCMs are a means for RF systems to convey the actual spectrum they are using to spectrum management systems.

The SCMs only capture the use of spectrum. In the spirit of defining a loose coupler, this standard deliberately does not define data that may be required in a spectrum management enterprise for regulatory, business, or security needs. As there are many business cases there can be many different versions of these latter data types. These additional data definitions should be defined as part of creating these enterprises and then may be combined with SCM data in the data exchanges that make the enterprise work. Keeping the SCMs pure allows many different enterprises to interact with each other with their own business-related

¹⁰ The word “convey” refers to the collection of data in a model to indicate a policy for using spectrum or a definition of a use of spectrum as opposed to the means to transmit such guidance or information.

data extensions while the SCMs remain the foundation for the collection of enterprises to arbitrate spectrum compatibility.

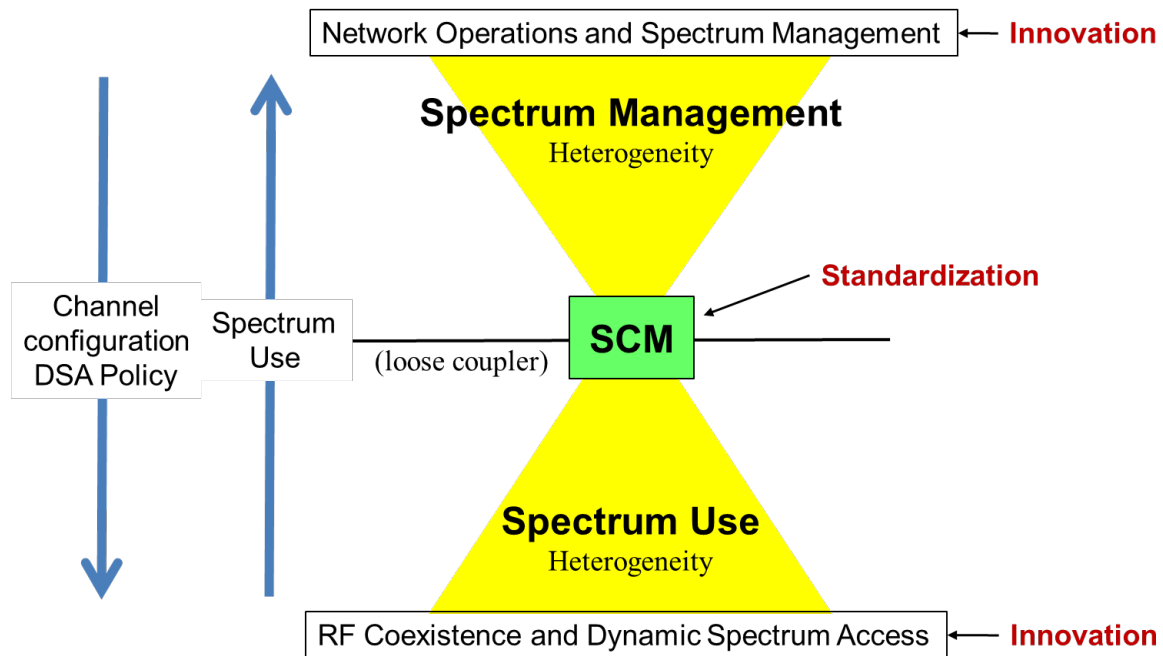


Figure 1—SCM as a loose coupler in spectrum management

5.4.3 Independent modeling of RF systems

Modeling does not require knowledge of peer systems. Users of systems can model their use of spectrum independently and then provide their models to the spectrum management enterprise so that their use of spectrum as conveyed in their model is considered in the assignment of spectrum to devices and systems. Knowledge of peer systems, however, is useful. Frequently, knowledge of peer systems allows modelers to call out modes of compatibility that are possible with those peer systems. For example, wideband networking systems may be compatible with low duty cycle signals that are typical of radars. In this case, modelers of the wideband networking system may want to specifically call out in their model the robustness of their system to this type of interference if they know the incumbent system is a radar.

5.4.4 Common methods for arbitrating compatibility of models

Spectrum consumption modeling is complemented with attendant methods of determining compatibility between models. These methods allow any two complete models to be assessed for their compatibility without dependence on any data other than that contained in their models. These computations have the same results anywhere in the spectrum management system. Thus, in modeling, the modeler has a clear understanding of the interpretation of what is included in the model.

5.5 Radio spectrum use policy

Spectrum use policies may have two parts, a permissive part identifying what the RF system may do and a restrictive part that constrains what the RF system may do. In the case of using SCMs for spectrum use policy, the models of incumbent users would be the restrictive part. Additional models can be used to convey the permissive part. Policies written using SCMs have the advantage that their compatibility with existing spectrum users can be verified using the algorithms of MBSM.

Spectrum use policy can be conveyed to RF systems in two ways, either as a direct or a dynamic authorization. The dynamic authorization is intended to allow competing systems to interact with each other's use of spectrum by announcing their use in models that become constraints to their peers. These methods differ in the computations expected at the RF system.

- *Direct Authorization:* The spectrum manager determines the requirements for compatible reuse and creates a set of permissive models of that compatible reuse. These models are given as policy to the dynamic spectrum access (DSA) systems. Components of the DSA system would simply determine where they are and the current time and lookup which models apply and so which channels can be used. If there are choices, they can use other criteria of their own to select which of the choices to use.
- *Dynamic Authorization:* Policy is conveyed using two types of models: *permissive models* (which are broad in scope) that describe the spectrum that might be considered and then *restrictive models* (which are the SCMs of spectrum use of other incumbent systems) that have precedence in spectrum use. The expectation is that the DSA system would make the computations that find a use within the broader permissive model that also respects the restrictions of the restrictive models. This approach can provide many more opportunities for reuse. From the spectrum manager's view, creating the models of the incumbent use is equivalent to writing restrictive policies for DSA use. A long-term permissive model can be augmented over time with short-term restrictive models as they are created for new uses.

Generally, SCMs enable location and time-based reuse of spectrum. The SCMPolicyOrProtocol construct of SCMs may be used to identify well-known behaviors and their operational parameters when a particular policy or protocol is known to be compatible with incumbent use. Modeling does not support the creation of these policies or protocols ad hoc.

6. Spectrum-dependent devices, systems, and sets

6.1 General

Clause 6 gives the bigger picture of spectrum consumption modeling. Spectrum consumption can be modeled for a device that uses spectrum, a system that uses spectrum that may consist of multiple devices, or a set of spectrum users that consists of multiple models of system and device use of spectrum. Models may provide the boundaries of what is being used or what may be used. Models may also be used to define the spectrum that is feasible to use.

6.2 Spectrum-dependent devices

6.2.1 General

A spectrum-dependent device (SDD) is a single physical component that emits radio frequency (RF) radiation, receives RF radiation, or both. Transmitter models capture the emission of radiation and receiver models capture the sensitivity of devices that receive radiation to interference. SDDs that perform both functions are modeled by a combination of transmitter and receiver models.

6.2.2 Transmitter models

A transmitter model captures the RF emissions of a transmitting device. This type of model identifies the possible locations of the device, the time of its operation, the spectral mask and power of its emissions, the directivity of its emissions, and in some cases behavioral information of the device. A proper transmitter SCM is a bound to the use of spectrum by the transmitter, that is the temporal, spatial, and spectral extent of the emission predicted by the model is greater than or equal to that of the actual device.

Details of the data requirements for a transmitter model are found in 9.1.

6.2.3 Receiver models

A receiver model defines the threshold boundaries for incompatible interference to a receiving device. This type of model identifies the possible locations of the device, the time of its operation, the spectral extent that it is sensitive to interference, the power level of interference it can tolerate, the directivity of its reception, its susceptibility to intermodulation (IM) effects, and, in some cases, behavioral information of the device. A proper receiver model SCM provides a limit to the interference that transmitter devices can cause in aggregate to the receiver model, that is a limit to the total interference in the temporal, spatial, and spectral limits of the modeled receiver's operation.

Details of the data requirements for a receiver model are found in 9.2.

6.3 System models

A system model is an SCM with a set of transmitter and receiver models that collectively capture the spectrum use of a spectrum-dependent system. A spectrum-dependent system may be an SDD or collection of SDDs. In SCM modeling a system model is used when the modeling of the use of spectrum requires more than what a single transmitter model or a single receiver model can capture. Thus, a system model is a container for multiple transmitter and receiver models that allows the modeler to associate multiple SDDs to a single system. Further, by placing transmitter and receiver models within the same system model, the modelers indicate that they do not constrain each other. For example, an SCM of a transceiver that transmits and receives in the same spectrum would consist of a transmitter model and a receiver model. Since they are part of the same system model, the transmitter and receiver models do not constrain each other.

System models are also used to capture the configuration options of a system. This type of system model provides the tunability of all SDDs within a system and the criteria for assigning channels to keep from causing self-interference. These types of models are used to record the spectral capabilities of systems and to convey channel assignment options that are feasible to fill a spectrum request for the system. A system model with CONFIGURATION_OPTIONS purpose is used to capture the full tunability of all SDDs of a system. They are usually a part of a repository of data on systems. A system model with REQUEST purpose is used to make a request for spectrum. These models will borrow from the CONFIGURATION-OPTIONS models but will differ in that they may not request all the feasible channels and they may convey the specific operational intent of the use, (i.e., where, when, and in what environmental conditions).

Systems may be composed of multiple SDDs that operate on different frequencies (e.g., a network with multiple links where each link uses a different frequency). Modeling systems that consist of multiple devices that separately operate on different frequencies requires a structure to show how they are related and work together. This standard provides three identification elements that assist in this differentiation: SystemID, XcvrName, and DeviceID. Their role follows:

- SystemID: An identification string that uniquely identifies the system. Modeling requires that no two independent systems have the same SystemID. All transmitter and receiver models within a system shall have the same SystemID.
- XcvrName: An identification string of transmitter and receiver models that are part of a system that operate on the same frequency. The XcvrName is unique within a system model for this single frequency operation but may be reused across different system models.
- DeviceID: An identification string of transmitter and receiver models that are part of the same physical component. DeviceID is unique within a system model but may be reused across different systems models. The combination of SystemID and DeviceID uniquely identifies a device from others among all systems.

Details of the data requirements of system models are found in 9.5.

6.4 SCM sets

An SCM set is a collection of system, transmitter, and receiver SCMs. Sets are used for the following five purposes:

- To collect all uses of spectrum within some boundary
- To provide spectrum that is available for use
- To identify constraints to spectrum use
- To capture the configuration options of a set of system
- To make a request for spectrum

The heading of a set defines the purpose of the set, that is, consumption, authorization, constraint, or request and the boundary within which it applies. The PropMapSelectionMethod field indicates the approach used to select which of a transmitter's or a receiver's propagation models to use in computing compatibility. The methods indicated by these choices are described in 10.5.4. A boundary may be spatial, temporal, and/or spectral. Further there may be an optional transmitter and receiver model in the heading that subsumes all the models within the set. This subsuming model allows for a quick check to determine if a system or device is compatible with the models listed in the set. Not being compatible with the subsuming model does not preclude spectrum use if the new use is compatible with all the individual models within a set. The source of the set defines its scope. For example, a consumption set provided by an enterprise might convey all spectrum used by the enterprise within the specified boundaries while a consumption set provided by a spectrum access system provider might list all spectrum uses it is aware within the boundaries of the set.

Details for the data elements of a set are explicitly presented in 9.6.

6.5 SCM messages

Communications between separate instantiations of systems based on the use of SCMs may be of any construct, model, or set. Each shall be complete in accordance with the applicable rules listed in Clause 13. This guidance makes no restriction on communications within SCM-based systems. Table 1 lists messages and common reasons to use them. This list does not restrict how these messages are used.

Table 1—SCM messages

Message type	Description
Construct	Message to communicate a part of a model which identifies a required, requested, chosen, or anticipated configuration, or indicates a current state of an aspect of a transmitter's or receiver's use of spectrum.
TxModel	Message with a single verified transmitter model. Used to provide an authorization to a transmitter or system, a description of a use of spectrum by a transmitter or system, or a request by a system to use spectrum.
RxModel	Message with a single verified receiver model. Used to communicate a constraint to the use of spectrum by a transmitter or system, used to communicate a request for receiver or system protection, or used to specify the level of protection a receiver or system will be provided.
SystemModel	A single system model capturing the full scope of spectrum use by the combination of one or multiple transmitter models and receiver models. A system model may be used to authorize, request, propose, or require a use of spectrum or identify how a system is using spectrum. It can be used as a constraint to the use of spectrum by another system.
SCMSet	Message to communicate a single set which contains one or multiple transmitter, receiver, or system models. A set may indicate how multiple systems may be configured, provide a set of requests being made by the message source, provide a set of authorizations to use spectrum, provide a set of constraints to the use of spectrum, or capture the collection of current, proposed, or anticipated uses of spectrum.

6.6 SCM data hierarchy

Figure 2 illustrates the hierarchy of spectrum consumption modeling. There are 11 constructs that capture the physical, operational, and environmental aspects of spectrum consumption that are used to build transmitter and receiver models. Clause 8 describes these constructs. System models may consist of multiple transmitter and receiver models capturing the spectrum consumption of one or multiple SDDs with a header that defines a larger boundary of the use of those SDDs. A set may consist of multiple system, transmitter, and receiver models with a header that defines the boundary of the set. Clause 9 provides a full description of transmitter, receiver, and system models and of model sets. Table 2 lists the header sub-elements of systems and sets and their further breakdown into sub-elements.

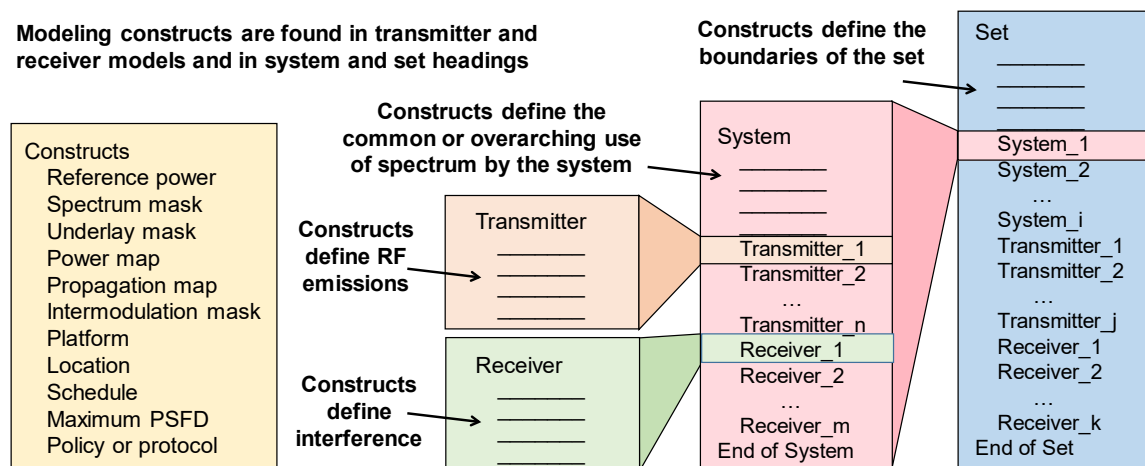


Figure 2—SCM hierarchy

Table 2—Header data elements for systems and sets

Data element	Sub-elements	Types	Enumerated values/ unit of measure	Occurrences	Notes
ID	—	String	—	1	Either SystemID or SCMSetID
Name	—	String	—	0..1	—
Purpose	—	Attribute	Varies based on use in systems or sets	1	See Clause 9
PropMapSelectionMethod	—	Attribute	CONSERVATIVE, RECEIVER_DOMINANT, OPTIMISTIC	1	Only used in set models; see Clause 9
Boundary	—	Structure	—	0..1	—
	BandList	Structure	—	0..1	Sub-elements in Table 11
	SCMSchedule	Structure	—	0..n	Sub-elements in Table 24
	SCMLocation	Structure	—	0..n	Sub-elements in Table 22
UberModel	—	Structure	—	0..1	—
	TxModel	Structure	—	0..n	Sub-elements in Table 27
	RxModel	Structure	—	0..n	Sub-elements in Table 28

7. Special data structures

7.1 General

This clause describes several special data structures used within more than one construct of SCM modeling.

7.2 Specifying confidence

7.2.1 General

Spectrum consumption modeling is used to convey anticipated use of spectrum. In many cases that use is uncertain and can vary. Modeling to capture the worst case helps ensure protection but does not fully convey opportunities for reuse and does not allow entities to negotiate spectrum sharing where some level of interference can be agreed to and modeled. Thus, SCM modeling allows the modeler to define multiple boundaries conditioned on some confidence the modeler has that those boundaries contain the full anticipated use of spectrum. The measure of *confidence* is a decimal number q such that $0 < q \leq 1$.

SCMs compatibility computations assume worst case use. The confidence element allows SCMs to be subdivided into parts that convey boundaries that attempt to define the likelihood that those boundary limits are reached. For example, a radio system that uses power adaptation may use something less than the maximum power in most use. The confidence measure could then be assigned to each of multiple power levels to indicate the likely fraction of time each power level is used. In another example, a modeler may not have full confidence that a mobile system will end up where it is planned to go. A confidence measure could be associated with each of multiple location models to indicate that uncertainty.

When confidence is used there is a necessary requirement to assess whether the model gives a full accounting of the range of possibilities. For example, if a model has a characteristic with 50% confidence there must still be an indication of what happens the remaining 50% of the time, if 30% for the characteristic then information on the 70% complement. The Group element supports identifying the constructs that use confidence that are checked together to meet this completeness requirement.

The causes for differing levels of confidence and the ways one boundary may apply over another are quite varied. For example, a confidence measure may indicate the likelihood a boundary is reached versus the percentage of time a boundary applies. For this purpose, several attributes accompany the likelihood measure when specifying confidence. They are as follows:

- The Approach attribute identifies whether the confidence measures indicate alternative conditions or a cumulative condition.
 - The *ALTERNATIVE* attribute indicates the confidence that one alternative or another is used. The sum of the confidences of the collection of common construct types using the alternative approach shall be 1.
 - The *CUMULATIVE* attribute indicates a series of constructs in which the higher probability constructs subsume the lower probability ones. At least one of the common constructs using the cumulative approach shall have the confidence of 1.
- The Nature attribute identifies whether the probability indicates that construct identifies a persistent or fleeting phenomenon.
 - Phenomena that move to a state with some probability and then stay there are *PERSISTENT*.
 - Phenomena that move freely from state to state, spending some fraction of their time in one state or another, are *FLEETING*. The attribute fleeting, by itself, is qualitative. To make it quantitative it is accompanied with a value for maximum dwell time. The maximum dwell time measure indicates the maximum amount of time that a system is in the state modeled. When used with the cumulative nature attribute, it indicates the time in state space between this state and the next lower probability state.
- The Derivation attribute provides additional information on how the value was determined.
 - *JUDGMENT* means that the value is the modeler's judgment.
 - *ESTIMATED* means the value was determined through a theoretical analysis.
 - *MEASURED* means the value was determined through a statistically appropriate method of measuring the phenomenon.

Table 3 provides a summary of the confidence data element.

Table 3—Confidence data element

Data element	Sub-elements	Types	Enumerated values/ unit of measure	Occurrences	Notes
Confidence	—	Structure	—	—	—
	Measure	Number	Dimensionless in (0, 1]	1	—
	Group	Integer	—	1	—
	Approach	Attribute	CUMULATIVE, ALTERNATIVE	1	—
	Nature	Attribute	PERSISTENT, FLEETING	1	—
	Derivation	Attribute	JUDGMENT, ESTIMATED, MEASURED	0..1	—
	MaxDwellTime	Number	Seconds	0..1	Required with FLEETING nature only

7.2.2 Standard confidence rules

The following are general rules for the use of the Confidence element.

When confidence is present in a list, construct or model, the collection of items containing confidence is broken up into “confidence groups.” For all items in a confidence group, the Approach and Nature shall be identical. Table 4 lists the constructs and models that have a Confidence element. All Confidence elements in the same Group shall have matching values on the binding elements. There is no ordering required for constructs using the same confidence group.

Elements without confidence count as a single group.

Table 4—Confidence binding and groups

Model/construct	Binding elements	Possible groups
ReferencePower	None	1
SpectrumMask	None	1..n
UnderlayMask	Unrated UnderlayMask and LeastConstraining	1
SCMPowerMap	LocationIndex	1
SCMPropagationMap	LocationIndex and AntennaHeight	1
SCMLocation	None	1..n
SCMSchedule	LocationIndex	1..n
TxModel	XcvrName and DeviceID	1
RxModel	XcvrName and DeviceID	1
TxOptionModel	XcvrName and DeviceID	1
RxOptionModel	XcvrName and DeviceID	1

Whenever the CUMULATIVE attribute is used, there shall be one item within the confidence group with a confidence of 1. All other items of the same type shall have a lower confidence level and no two items in the confidence group may have the same confidence level. Items with lower confidence are assumed to fit within the items of higher confidence.

Whenever the ALTERNATIVE attribute is used, then the confidence levels among the items in the confidence group shall add to 1.

Subclause 11.4 describes the role of confidence in determining compatibility among models.

7.3 Specifying values by direction

The data structures that are used to specify parameters by direction are referred to generally as SCM maps. It is called an SCM map because it assigns values to sectors on a sphere like coloring countries on a map on a globe. The data of an SCM map is a vector that lists azimuths, elevations, and the model parameters in a prescribed order so there is no ambiguity as to which elements in the vector represent what type of value. A complete map specifies a set of model parameters toward all directions. The vector of values starts with elevations (ϕ) from the vertical down direction -90° and reaching to the vertical up direction 90° , and azimuths (θ) reaching about the node on the horizon. The first and last azimuths point in the same direction, that is, 0° and 360° . The vector uses two elevations to define a spherical annulus about a node and then a series of the model parameter sets and azimuths that specify different model parameters on that annulus by sector. One or multiple annuli are defined ultimately to define parameters for all directions. The number and spacing of elevations and azimuths that are listed in the vector is arbitrary and used as necessary to provide resolution. The form of the vector is as follows:

$$(-90^\circ, 0^\circ, p_{0,0}, \theta_{0,1}, p_{0,1}, \theta_{0,2}, \dots, 360^\circ, \phi_1, 0^\circ, p_{1,0}, \theta_{1,1}, \dots, 360^\circ, \phi_2, 0^\circ, p_{2,0}, \dots, p_{last}, 360^\circ, 90^\circ)$$

Figure 3 illustrates an interpretation of this vector. The vector starts in the -90° elevation and the 0° azimuth, and an annulus is specified for each pair of elevations and so from -90° to ϕ_1 and from ϕ_1 to ϕ_2 and so on. These elevations bound a series of values alternating between model parameters and azimuths. In this example, the model parameter set has just one value, p . Each model parameter $p_{i,j}$ applies to the sector that reaches from elevation ϕ_i to ϕ_{i+1} and from azimuth $\theta_{i,j}$ to $\theta_{i,j+1}$. For example, in Figure 3, the model parameter $p_{1,0}$ applies from elevation ϕ_1 to ϕ_2 and from azimuth 0° to $\theta_{1,1}$.

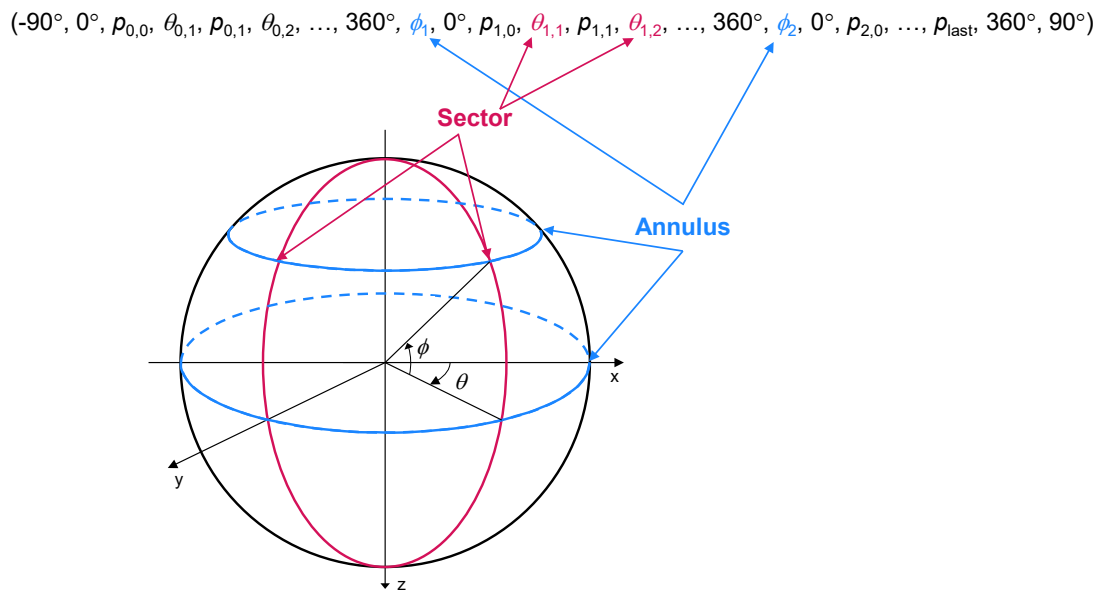


Figure 3—Example of the map vector used in propagation and power modeling

The map vectors are variable in length depending on the resolution desired. When there is just one value specified for all directions, the vector has five values, $(-90^\circ, 0^\circ, p_{0,0}, 360^\circ, 90^\circ)$. By following the order convention of this vector, modelers can verify a model parameter is assigned to all directions and reduce the size of the data recorded.

This data structure is used to describe directional differences in propagation and in antenna gain and to describe the steering of antennas. The variables used are typical for spherical coordinate systems to indicate direction and the orientation of the axes match how azimuth and elevation are perceived on the surface of the Earth. The convention most often used to define antenna patterns uses these same variables, θ and ϕ , but in an opposite sense. The variable θ is used to indicate the angle of a pattern from the positive z-axis where the z-axis is the boresight of the antenna and ϕ measures the angle around the boresight. Angles in this antenna format shall be converted into the angles of the format of Figure 3 keeping the same axes.

Table 5 shows that an SCMap consists of a vector of values found in a structure. The value sub-element chosen from the structure indicates its role and for directional angles the range of possible values. There is not an SCMap data type but rather an SCMPowerMap, ScanningRegion, or SCMPropagationMap type that are described in 8.5 and 8.6, respectively.

Further, the model parameter above may be a structure that consists of multiple parameter values required for a single model. This is the case for the SCMPropagationMap.

Table 5—SCM map data

Data element	Sub-elements	Types	Enumerated values/ unit of measure	Occurrences	Notes
SCMap	—	Structure	—	—	—
	Map Value	Structure	—	5..n	Order is important to capture the solid angle and directional value for the model. Refer to 7.3 for better details of values and their order.
Map Value	—	Structure	—		Choice of one of the following options
—	Elevation	Number	Degrees from -90° to $+90^\circ$	1	—
—	Azimuth	Number	Degrees from 0° to 360°	1	—
—	Gain, Model, or Boolean	Number Structure Boolean	—	1	—

7.4 Spectral masks

Masks are used in multiple contexts of spectrum consumption modeling. They are used to articulate the spectral content of transmissions, the spectral sensitivity of receivers, and the susceptibility of both transmitters and receivers to IM effects. A mask consists of a list of tuples, called a ControlPoint in the data structure, consisting of a frequency and a relative power. These control points are ordered from lowest to highest frequency. The frequencies are relative to a reference frequency, usually the center frequency of the mask. The relative power values are either spectral power spectral densities, (dB/bandwidth) in masks for interference and interference susceptibility or just relative power (dB) in IM masks. The number of control points in a list is arbitrary. Below is a mask where frequencies are explicitly listed. The equivalent mask using relative frequencies follow, and the relative frequencies are the offset from a reference frequency:

$$[(400 \text{ MHz}, -60 \text{ dB}), (401 \text{ MHz}, 0 \text{ dB}), (409 \text{ MHz}, 0 \text{ dB}), (410 \text{ MHz}, -60 \text{ dB})]$$

$$f_c = 405 \text{ MHz}, [(-5 \text{ MHz}, -60 \text{ dB}), (-4 \text{ MHz}, 0 \text{ dB}), (4 \text{ MHz}, 0 \text{ dB}), (5 \text{ MHz}, -60 \text{ dB})]$$

If these masks include a value for resolution bandwidth (RBW), then the power term is applied to that bandwidth for a power spectral density. It is used in all masks except for IM masks. Table 6 lists the data in a mask. Throughout this standard, example masks are given in the actual frequency format to simplify descriptions but must be converted to the relative frequency format to follow this standard.

Table 6—SCM mask data element and control points

Data element	Sub-elements	Types	Enumerated values/ unit of measure	Occurrences	Notes
SCMMask	—	Structure	—	—	—
	RefFrequency	Number	Megahertz (MHz)	1	A positive value except when used within the Tunability element (see Table 36, Table 29, and Table 30) where –1 indicates choose from tunability options.
	ControlPoint	Structure	—	2..n	In ascending frequency order.
ControlPoint	—	Structure	—	—	—
	Frequency	Number	Megahertz (MHz)	1	A frequency offset from RefFrequency above.
	RelativePower	Number	Decibel (dB)	1	Power relative to Reference Power.

8. Modeling constructs

8.1 General

The 11 modeling constructs of spectrum modeling are the fundamental building blocks of SCMs. Each construct has a purpose, but it is how the multiple constructs are combined and assembled that ultimately makes the SCM. Some constructs may be found in every model such as reference power while other constructs may be used infrequently such as the policy or protocol construct. Some constructs may appear multiple times in the same model.

The meaning of each construct, how each is used to articulate an aspect of spectrum use, how they interact with each other to yield a comprehensive model of use, and how the information contained within the constructs is used to determine compatibility among models is the very the core of spectrum consumption modeling.

This clause serves multiple purposes. It defines the purpose of each construct and the role each construct would play in a model. It describes how the construct interacts with other constructs to capture phenomena of spectrum consumption. It defines the construct data elements that are in models. It describes some known exemplary best practices of the use of each construct data element.

8.2 Reference power

8.2.1 General

The reference power is a reference power level for a model. It is the only data element within a model that is a power value, that is, a value in decibel watt (dBW). Power elements in other constructs are relative to this value and have units of decibels (dB).

8.2.2 Purpose and use

The purpose of the ReferencePower construct is to provide a reference power level for the emission of a transmitter in a transmitter model or to provide reference power level for the allowed interference in a receiver model. However, the reference power term is modified by multiple other constructs that capture the phenomenology that define how the power is distributed spectrally and spatially. They ultimately convert the total power to a PSFD. Generally, modeling follows the physics of the problem so that modeling is natural. In this case, the reference power in a transmitter would be the power level that drives the antenna. The reference power in a receiver could be the total amount of interference that a receiver can tolerate after frequency and time dependent rejection. Modeling, however, is artful and the reference power term can be adjusted with corresponding adjustments in other constructs to yield the same boundaries of use but to obfuscate the specific operating parameters of the modeled system.

Many systems, specifically broadband systems, employ power control. The powers used by individual transmitters are managed to achieve reliable reception at a base station while minimizing system wide interference among the plurality of base stations in the system. As a result, power levels may vary with some distribution. The ReferencePower construct provides a means to capture this variability using the Confidence data element. The Confidence element shall be ignored in computing compatibility unless the receiver model uses multiple reference powers to qualify the underlay masks or there is a peer-wise agreement on how the element is considered in spectrum sharing arrangements. The default compatibility computation is to use the highest power in the distribution.

8.2.3 Data elements and their meaning

The data structure consists of two single real numbers, one for the power level and one for the confidence. The use of confidence is optional. If confidence is not used, then there would be a single power term. If confidence is used, the confidence may be ALTERNATIVE or CUMULATIVE and PERSISTENT or FLEETING. If the FLEETING attribute is used, then a value for the maximum dwell time of the FLEETING event is also required. The model construct will have multiple <Power, Confidence> tuples. Most models are likely to use the CUMULATIVE and FLEETING attributes. If the confidence term is used, then all masks shall have the same attributes. The confidence requirements of 7.2.2 still apply. By default, the highest power level at transmitters and the lowest power level at receivers are used in compatibility computations regardless of confidence level. Special arrangements outside the scope of this standard must be established to do otherwise.

If a single power level is used, then the data is a numerical value with power in units of decibel watt (dBW). Table 7 lists the data elements of the ReferencePower construct.

Table 7—SCM reference power construct

Data element	Sub-elements	Types	Enumerated values/ unit of measure	Occurrences	Notes
ReferencePower	—	Structure	—	—	—
	Value	Number	Decibel watt (dBW)	1	—
	Confidence	Structure	—	0..1	Used when there is more than one relative value in a model. See Table 3 for description.

If multiple power levels with different levels of confidence are used, then there would be multiple power and confidence tuples, for example, $\langle \text{Power}_0, \text{Confidence}_0 \rangle$, $\langle \text{Power}_1, \text{Confidence}_1 \rangle$, ... $\langle \text{Power}_n, \text{Confidence}_n \rangle$. Expanding the confidence to include attributes, the tuples could be complemented with three attributes and a maximum dwell time value. As an example, assuming the combination $\langle \text{Power}, \text{Confidence}, \text{Approach}, \text{Nature}, \text{MaximumDwellTime}, \text{Derivation} \rangle$, consider the following list:

- $\langle 0.025 \text{ dBW}, 1, \text{CUMULATIVE}, \text{FLEETING}, 0.000004 \text{ s}, \text{MEASURED} \rangle$
- $\langle 0.020 \text{ dBW}, 0.9, \text{CUMULATIVE}, \text{FLEETING}, 0.000004 \text{ s}, \text{MEASURED} \rangle$
- $\langle 0.015 \text{ dBW}, 0.75, \text{CUMULATIVE}, \text{FLEETING}, 0.000004 \text{ s}, \text{MEASURED} \rangle$
- $\langle 0.010 \text{ dBW}, 0.3, \text{CUMULATIVE}, \text{FLEETING}, 0.000004 \text{ s}, \text{MEASURED} \rangle$
- $\langle 0.005 \text{ dBW}, 0.1, \text{CUMULATIVE}, \text{FLEETING}, 0.000004 \text{ s}, \text{MEASURED} \rangle$

This list show that 100% of the time the power is $\leq 0.025 \text{ dBW}$, 90% of the time $\leq 0.020 \text{ dBW}$, 75% of the time $\leq 0.015 \text{ dBW}$, 30% of the time $\leq 0.010 \text{ dBW}$, and 10% of the time $\leq 0.005 \text{ dBW}$. It shows that the maximum dwell of a transmission within the range of 0.020 dBW and 0.025 dBW is 4 μs . The modeler likely means that no transmission lasts longer than 4 μs and only 10% of the transmissions are within this power range.

8.2.4 Modeling requirement

Every transmitter and receiver model shall have a reference power value. The use of the confidence measure is optional. For confidence to affect compatibility computations there shall be a peer-wise agreement on how compatibility is to be computed using the confidence measures. Without an agreement, the highest power level in a transmitter model is used and the lowest power level in a receiver model is used in compatibility computations.

8.3 Spectrum mask

8.3.1 Purpose and use

The purpose of the SpectrumMask construct is to convey the spectral content of RF emissions and their power spectral density. RF signals occupy a band of spectrum and may extend beyond the nominal bounds of their channel or fit well within that channel. The spectrum mask attempts to convey the bounds to the spectral content of the signal. This construct enables SCMs to be used to determine when adjacent band interference occurs.

In a frequency hop system, transmissions are not persistently on a single channel and so offer an opportunity for other systems operating in the same frequency bands of the hopping to coexist. In this case, the spectrum mask captures not only the spectral content of a signal at an instant but also the statistical characteristics of its

hopping. Varying amounts of detail about the hopping can be provided. Subsequent determination of harmful interference on coexisting systems depends on the modeling of the receiver's susceptibility to this interference in its underlay mask. The frequency hopping spectrum mask serves only to capture the nature of the frequency hopping. The basic content is the generic spectral content of a signal, the channels or frequency bands through which these signals hop, the dwell time of a signal at a hop, and then the average period between hops. In cases where the signal space varies at individual hops or when the dwell time varies, modelers have the choice to use multiple spectrum mask data structures to capture the variation in these characteristics.

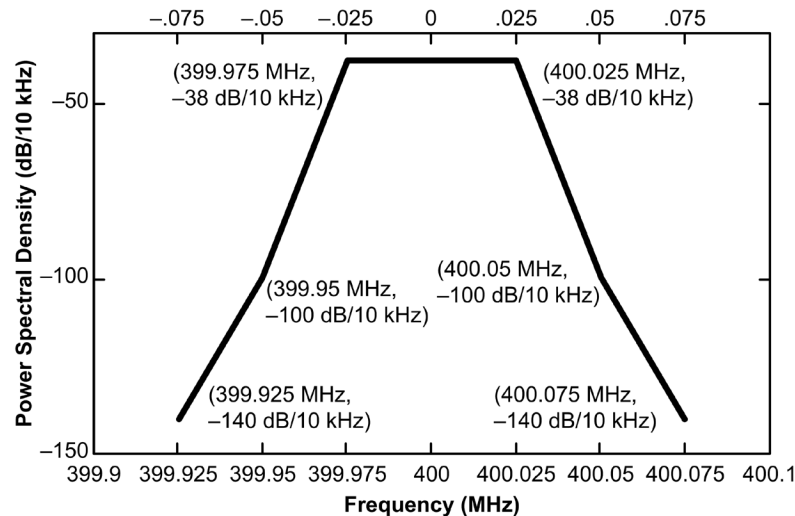
8.3.2 Data elements and their meaning

Spectrum masks use the spectral masks described in 7.4 with an RBW to indicate the bandwidth over which the specified power level of the mask is spread. The power term in spectrum masks is a relative power referenced to the ReferencePower construct of the model. Together, the reference power, the relative power of the mask, and the bandwidth resolution specify the spectral density of power (i.e., power per unit bandwidth) at each frequency covered by the mask. The spectral density power levels for all frequencies outside the frequency band covered by the mask are assumed to be less than or equal to those at the closest end of the mask.

If the reference power accurately represents the power of transmission, then the highest power in a spectrum mask will be beneath 0 dB since a power spectral density with an RBW that is a fraction of the total bandwidth of a signal has only a fraction of the total power. For example, if the bandwidth of a signal is 1 MHz but the RBW is just 10 kHz, then the relative power reduction within the RBW would be determined to be as follows:

$$p = 10 \cdot \log \left(\frac{10 \text{ kHz}}{1 \text{ MHz}} \right) = -20 \text{ dB}$$

Figure 4 illustrates an example of a spectrum mask and first provides a mask with actual frequencies followed by its representation using the relative frequency approach of the standard as described in 7.4.



Actual frequencies: $\langle (399.925, -140), (399.95, -100), (399.975, -38), (400.025, -38), (400.05, -100), (400.075, -140) \rangle$ RBW = 10 kHz

Relative frequencies: $\langle (-0.075, -140), (-0.05, -100), (-0.025, -38), (0.025, -38), (0.05, -100), (0.075, -140) \rangle$ $f = 400 \text{ MHz}$, RBW = 10 kHz

Figure 4—A spectrum mask specified using relative frequencies in the control points

Frequency hopping systems require the modeling of the signals that are transmitted and the characteristics of the frequency hopping. The spectrum mask provides the shape of the signal but the reference frequency in the data structure is ignored. It is replaced by frequencies in the hopping data. The spectrum mask is complemented with details on the frequency hopping, specifically, the channels used, the dwell time, and the average period between hops. There are two options for specifying the frequencies used: a listing of the specific reference frequencies such as $(f_0, f_1, f_2, \dots, f_x)$ or a listing of the end frequencies of the bands that are used. In the second case, the tuple (f_{b1}, f_{e1}) define the beginning frequency and ending frequency of a band. A collection of disjoint bands is specified through a series of frequency pairs such as $\langle (f_{b1}, f_{e1}), (f_{b2}, f_{e2}), \dots, (f_{bx}, f_{ex}) \rangle$. In this modeling the reference frequency for the relative spectrum mask is equally likely anywhere within a specified band. The relative spectrum mask and the frequency specifications are paired with two additional data elements that define the frequency hopping. The first is the dwell time and the second is the hop period. The dwell time refers to the duration of time that a signal dwells on one of the center frequencies before the next hop. The hop period specifies the average time between transmitted signals (i.e., the time between the start of each subsequent frequency hop).¹¹

The modeling of single frequency pulsing systems uses the HoppingData element. In this case, the frequency list would have a single frequency.

Transmitter models may have multiple spectrum masks. When those models are not confidence rated, they exist concurrently and collectively cause interference to receiver models. Using multiple transmitter models may be appropriate to capture the different pulse widths a radar might generate or different bandwidths a frequency hopping system might use. Each mask would have its own DwellTime and HopPeriod which indicates the fraction of time the system is transmitting one type of signal over another. If the system may hop in one mode or the other but not concurrently, then confidence may be used in the modeling to indicate the fraction of time it is in one mode or the other. If two or more modes of transmission happen concurrently and each mode has characteristics that vary with some level of confidence, then separate confidence groups may be established, one group for each mode. Subclause 11.4.2 further describes the use of confidence groups.

Transmitters may have operational characteristics where they may be in one state or another with some probability. For example, electronically steered radars may move from a scanning mode to a tracking mode. A receiver in the tracking direction would perceive a much greater pulse rate. An alternative confidence measure can be used to convey the likelihood that this receiver would perceive one or the other of the modes. These differences in operation may make a difference in whether a secondary system would take the risk of using the channel.

Spectrum masks may also be created with cumulative probabilities. The confidence measure would define the likelihood that transmissions in a system fall within the boundary of the mask. A system may consist of radios from different manufacturers that vary in their quality, some allowing more leakage of signals into adjacent bands. The cumulative confidence measure would show that the boundary of the masks of the poorer performing transmitters subsumes the boundaries of the masks of the better performing transmitters.

When used, confidence measures are associated with individual masks. In these cases, transmitter models would have multiple masks. All masks in the same confidence group shall use the same confidence approach, either alternative or cumulative, and the same confidence nature, persistent or fleeting.

Table 8 lists the data elements in the SpectrumMask construct. All masks have the mask itself, SCMMask, and a resolution bandwidth, ResolutionBW. The HoppingData element is added when the spectrum mask is for a frequency-hopping or a pulsing type of signal. Table 9 lists the data element of this data object. HoppingData provides a dwell time, DwellTime, and a hop period, HopPeriod, and then either a frequency list, FrequencyList, which is further defined in Table 10, or a band list, BandList, which is further defined in Table 11.

¹¹ In most cases hopping occurs at a uniform interval but in those cases where there is some jitter, average time is used.

Table 8—SCM spectrum mask construct

Data element	Sub-elements	Types	Enumerated values/ unit of measure	Occurrences	Notes
SpectrumMask	—	Structure	—	—	—
	HoppingData	Structure	—	0..1	If used, indicates mask is for a frequency hopping or pulsing signal. Replaces RefFrequency in SCMMask. Sub-elements in Table 9.
	ResolutionBW	Number	Megahertz (MHz)	1	The RBW of the mask indicating the bandwidth across which the indicated power is disbursed.
	SCMMask	Structure	—	1	A spectrum mask. See Table 6.
	Confidence	Structure	—	0..1	Used in a model with multiple masks showing likelihood of variation in spectral content. See Table 3 for the data description.

Table 9—SCM hopping data

Data element	Sub-elements	Types	Enumerated values/ unit of measure	Occurrences	Notes
HoppingData	—	Structure	—	—	—
	DwellTime	Number	Seconds	1	Max duration of a signal.
	HopPeriod	Number	Seconds	1	Time between signal starts of subsequent hops.
	Choose one of the following				
	FrequencyList	Structure	—	1	Sub-elements in Table 10. If used, provides reference frequency of the SCM Mask. When hopping data is part of a configuration options or request model with frequency tunability information, a single frequency is set to –1. (See 9.3, 9.4, 9.5.2.2, and 9.5.2.3.)
	BandList	Structure	—	1	Sub-elements in Table 11. If used, the reference frequency of the SCMMask may be anywhere in the listed bands.

Table 10—SCM frequency list

Data element	Sub-elements	Types	Enumerated values/ unit of measure	Occurrences	Notes
FrequencyList	—	Structure	—	—	—
	ReferenceFreq	Number	Megahertz (MHz)	1..n	—

Table 11—SCM band list and band

Data element	Sub-elements	Types	Enumerated values/ unit of measure	Occurrences	Notes
BandList	—	Structure	—	—	—
	Band	Structure	—	1..n	—
Band	—	Structure	—	—	—
	StartFrequency	Number	Megahertz (MHz)	1	Lower frequency of a band
	EndFrequency	Number	Megahertz (MHz)	1	Upper frequency of a band

8.3.3 Modeling requirement

All transmitter models have a spectrum mask. The spectrum mask is used together with the reference power and a power map to specify the PSFD in any direction from a modeled transmitter.

Spectrum masks are intended to support not only in-band but also out-of-band compatibility computations. Computation of compatibility depends on the extent of spectrum modeled by the spectrum mask. Ideally, the spectral breadth of a spectrum mask should be broad enough that the powers at the end points are beneath the ambient noise floor at the locations they are considered for compatibility. In cases where the mask does not reach this level, it can only be assumed that the signal outside the mask is something less than that of the end points. For the purposes of compatibility computations when using the total power method in computing the mask power margin, the level of the endpoints are assumed for all frequencies beyond the endpoint for frequencies covered by any overlapping underlay mask.¹² There is an advantage to specifying frequency content well beyond the channel bandwidth. The extension of spectrum mask endpoints does not apply when the underlay mask is defined for the maximum power density method for computing the mask power margin.

The determination of compatibility using the spectrum mask depends on the underlay masks used in models of the systems with which spectrum is shared. The modeling of the details of frequency hopping or short duty cycles allows use of underlay masks that match these characteristics and allow either higher levels of power in the transmitting system or for the receiving system modeled in the underlay to be closer in proximity to the transmitting system. The method for determining compatibility depends on the masks used to model both systems. Subclause 10.6 describes the power margin computations that account for the interaction of spectrum masks with underlay masks. When masks are frequency hopping, the power in the combination of the reference power and spectrum mask shall specify the signal's peak power.

¹² This rule attempts to account for the use of masks that were built to show in-band spectrum use only. It is expected that with time, spectrum masks will extend beyond in-band representations to fully show the potential for out-of-band interference with end points where out-of-band interference is unlikely.

8.4 Underlay mask

8.4.1 Purpose and use

The UnderlayMask construct together with the ReferencePower construct defines what is considered incompatible interference. They are selected to provide an interference margin that protects reception in a system. Additionally, underlay masks may be used to define the conditions that a new user must accept to use the spectrum. In this case, the underlay mask defines the maximum power level of the anticipated interference as a function of frequency that the new user must accept. The rest of this discussion assumes the masks are used to define incompatible interference.

Underlay masks specify the power spectral density that a receiver can tolerate from a remote interfering transmitter. It conveys both the power level of tolerable interference and the spectral sensitivity to interference. In the latter case, the underlay map conveys the filtering by frequency that the receiver performs. Like the spectrum mask, it is a piecewise linear graph of relative power versus frequency combined with an RBW to specify the spectral resolution. A single underlay mask may apply to any signal of any bandwidth, or a model may provide multiple underlay masks each for different conditions of interference differentiated by the spectral and temporal nature of interfering transmissions.

An underlay mask may be used in either a receiver model or a transmitter model. When used with a receiver model, relative power in these masks is relative to the reference power in a receiver model for all locations of the receiver model. When used within a transmitter model, the relative power in the underlay mask is assumed to adjust as that of the spectrum mask because of antenna directivity and propagation and so it indicates a constant protection margin with the spectrum mask of the transmitter model. In this latter case, when the underlay mask is part of a transmitter model, it is referred to as a *spectrum-mask-referenced* underlay mask or simply a referenced model. The use of an underlay mask with a transmitter model can simplify the modeling of broadcast systems where there is a single transmitter. The protection of the receivers is based on the effective range of the broadcast.

Figure 5 illustrates the difference between these masks. Figure 5(a) illustrates a mask that uses a transmitter spectrum mask as a reference and Figure 5(b) illustrates a similar mask that would apply to a location. The constraints of the first provide a protection margin relative to the spectrum mask and the constraints of the second are fixed for all locations. The frequency terms of the two are the same but power terms of the mask referenced to a location are much smaller.

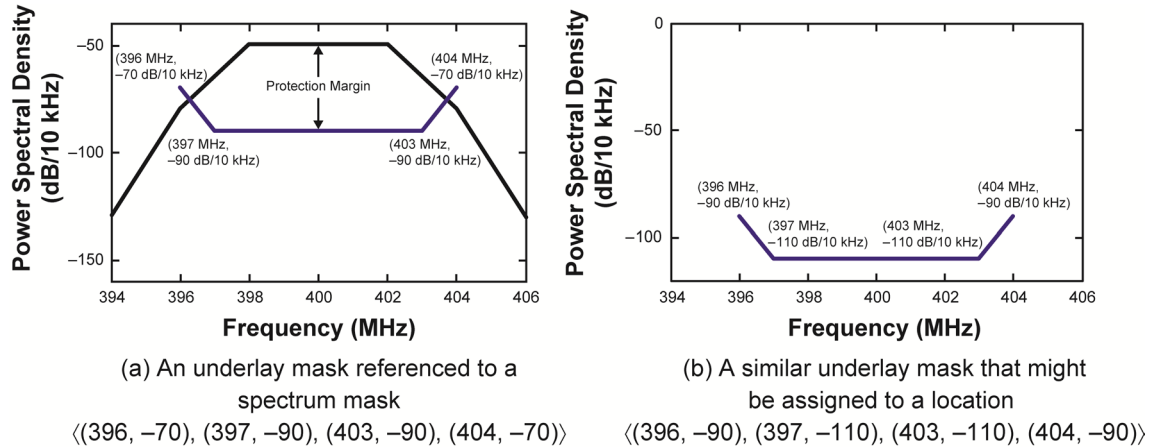


Figure 5—Comparison of underlay masks with alternative references, spectrum mask, and location¹³

A receiver model may use multiple underlay masks to indicate differences in sensitivity based on the duty cycle, frequency hopping or behavior of the radios causing interference. They are rated for the different conditions.

There are also systems that can tolerate interference from certain low duty cycle signals that might be transmitted from radars and some other low duty cycle frequency hop systems. These masks are rated with a duty cycle and a maximum dwell time for the signals in that duty cycle.

Receivers in a frequency hopping system may be able to tolerate some level of interference if it only affects a portion of the hops the receiver traverses. This assumes the receivers are not staring receivers observing a band but hopping receivers that tune their filters with each hop. Modelers can create underlay masks that convey the susceptibility to interference at each hop where interference is accepted if below a threshold of some number of hops or fraction of time.

A receiver system may be able to coexist with another RF system because of the unique protocols or policies implemented in that system that are effective at reducing interference to the modeled receiver. Examples include medium access control mechanisms that do not allow transmission when the receiver channel is in use, a dynamic frequency selection policy that shifts frequencies to elude an active use of spectrum, or an adaptive technology such as smart antennas that are effective at nulling emissions in the direction of the receiver. Modelers can indicate greater resilience to these systems by adding underlay masks to receiver models that are matched to the Protocol of Policy that a coexisting system may implement.

Modelers use these collections of masks to convey additional opportunities for spectrum reuse. In determining compatibility, the assessment uses the underlay mask with the least restriction for which the interfering transmitter model meets the criteria of its use, for example, bandwidth, duty cycle, matched protocol.

8.4.2 Data elements and their meaning

Underlay masks use the spectral masks described in 7.4 with an RBW to indicate the bandwidth over which the specified power level of the mask is spread. The power term in spectrum masks is a relative power referenced to the reference power of the model. Together, the reference power, the relative power of the

¹³ Frequencies of these masks are relative in the actual mask construct. So rather than 396, 397, 403 and 404 MHz for the control point frequencies, the mask definition would start with a reference frequency then the relative difference in frequency in each control point. As an example, in the case $f_{ref} = 400$ MHz and the values in the control points are -4 MHz, -3 MHz, 3 MHz, and 4 MHz.

mask, and the RBW specify the spectral density of power (i.e., power per unit bandwidth) at each frequency covered by the mask. The modeler specifies the extent of frequencies that a receiver is sensitive to interference by explicitly modeling that extent. In assessing compatibility there are no assumptions made about the susceptibility to interference outside the frequency limits of the mask.

Underlay masks convey both the power of allowed interference and the frequency dependent filtering of the receiver. The mask is presented graphically to indicate the allowed power of an interferer as a function of frequency. This portrayal makes it very easy to compare the relative performance of different receiving systems. By convention, the total power allowed by the underlay mask in the lower 3 dB bandwidth of the mask conveys the total allowed interference. The difference in relative power at a point of the mask with respect to the relative power in the passband of the underlay mask (i.e., the lowest power of the mask) indicates the frequency dependent attenuation of the filtering of the receiver.

The computation of the power margin from the interaction of an interfering transmitter spectrum mask and an underlay mask may be of two types: total power or maximum power density. The total power computation uses the underlay mask to assess the quantity of power that would enter the receiver and cause interference. The maximum power density computation assesses whether the maximum power spectral density of a transmitter spectrum mask exceeds any threshold level of the underlay mask. The advantage of the maximum power density method of computation is that it simplifies the assessment of aggregate effects. The assumption is that the power level of the underlay mask has been set in anticipation of the types of aggregate interference that might occur. Compatibility computations and decisions can be made with just the pairwise comparison of the underlay mask with each interferer. The total power method, however, only determines the individual contribution of interference from a single interferer. Admission decisions require the determination of the aggregate interference from all interferers. This aggregate interference must be less than the allowed interference of the receiver model. Thus, for a new use to be compatible, its interference in aggregate with all other interference shall be less than the allowed interference conveyed in the receiver model.

Underlay masks are scaled in combination with the reference power to identify the interference tolerance of the receiver. These two constructs indicate the modeler's chosen criterion for the interference tolerance for compatibility assessments (See 10.6.). The interference threshold, I_{Th} , indicated by the reference power and underlay mask is computed as

$$I_{Th} = ReferencePower + U_{3dB}$$

where U_{3dB} is the power under the 3 dB bandwidth of the underlay mask (See 10.6.2.2, Step 1). It indicates the modelers choice for interference tolerance and is the value used in determining compatibility of systems. However, there are cases where modelers would want these thresholds to change conditionally. The underlay mask data structure allows four optional values to be included in a model to support these alternatives. They are Noise, SINR, I2Nratio, and I2Sratio. Noise is the noise floor of the receiver and is in units of decibel watt (dBW). A modeler provides this value to simplify the computation of I2Nratio and the SINR criteria for interference tolerance. I2Sratio is independent of the Noise level.

I2Nratio refers to the I/N criteria. The reference power and power levels of the underlay mask in models designed to support spectrum management are typically chosen to reflect I/N constraints. It is entered as the decibel value of that ratio. This value is added to the Noise level of the receiver to get the interference threshold.

$$I_{Th} = Noise + I2NRatio$$

SINR is the minimum signal to interference plus noise ratio. It indicates a criterion for interference tolerance based on knowledge of the expected signal strength of the desired signal. Potentially, it provides a greater tolerance to interference than the I/N criterion. Upon determining the expected signal strength in decibel watt (dBW) at a receiver, S , the interference threshold is computed as:

$$I_{Th} = 10 \log \left(10^{\frac{(S-SINR)}{10}} - 10^{\frac{Noise}{10}} \right)$$

The I2SRatio specifies a criterion where the interference threshold is a fixed ratio to the signal strength, S. Typically the I/N and SINR criteria identify cases where the system is free from harmful interference. There is often an interference range where a system may still perform but at a degraded level (e.g., a communication system that modifies modulation and coding to seek resiliency to interference resulting in a lower bitrate). The I/S criterion identifies the limit to that range where the system can no longer function. Given the expected signal strength at the receiver in decibel watt (dBW), the interference threshold is computed as follows:

$$I_{Th} = S + I2SRatio$$

Upon computing a new interference threshold, the reference power or the power levels of the underlay mask must be adjusted as in the following:

$$I_{Th} = ReferencePower + U_{3dB}$$

A receiver model may have multiple underlay masks that are used based on matching them to the characteristics of the interfering signal. Some masks may describe a use that does not add in aggregate to interference. They are identified with the Independent flag. A transmitter that meets the criterion of an underlay mask with the Independent flag is permitted to operate with the modeled receiver based on that criterion alone.

The independent flag is typically used with underlay masks rated with a policy or protocol. These masks show that a transmitting system using the policy or protocol can coexist without causing interference because of its behavior. For this reason, it does not contribute to aggregate interference.

A receiver model may have underlay masks that indicate different constraining concepts, most and least constraining as described in 10.11 and 10.12. The presence of the LeastConstraining flag indicates the use of the least constraining method, otherwise use the most constraining point computations. Models may have underlay masks of both types, but they are not used together. Least constraining underlay masks are used to indicate the strength signals must be to achieve an objective across the receiver location such as the necessary signal strength for reception across the location. The primary goal of modeling is to manage interference which is a most constraining concept. The least constraining concept is available for extended uses of models to manage signal quality and is ignored in managing interference. If a model only has underlay masks with the LeastConstraining flags, they are ignored in most constraining point computations.

See 8.4.3 and 10.13.2.1 for additional restrictions on the use of multiple underlay masks in the same receiver model.

Underlay masks may be rated for low duty cycle interference. It may be used with underlay masks that use either the maximum power density or total power methods for power-margin computations. The single mask is given several ratings that combine duty cycle, maximum dwell time and a power level adjustment of the form $\langle (DC_0, DT_0, p_0), (DC_1, DT_1, p_1), \dots, (DC_n, DT_n, p_n) \rangle$. These masks identify two constraints that define the duty cycle limitation. The duty cycle (DC in Figure 6) identifies the total fraction of time the interferer is present and maximum dwell time (DT in Figure 6) identifies the maximum continuous period of time that an interfering signal is on. When multiple low duty signals arrive from distant interferers, margin computations add their duty cycles and add their dwell times for these criteria to select the correct mask. DC rated masks regulate the power of the worst-case interfering signal as opposed to the average of the low duty cycle signals which the unrated underlay mask regulates. See 10.6.2.5 and 10.6.2.6.1 for guidance on the use of DC rated masks.

Figure 6 illustrates examples of rating masks for a duty cycle using a single mask approach. A mask is provided with lists of duty cycle, maximum dwell time, power adjustment, three-tuples that create a collection of underlay masks where the adjustment operates on all power levels of the base mask. Note that there is a base mask that accounts for interfering signals that cannot meet the criteria of any of the duty-cycle-rated masks.

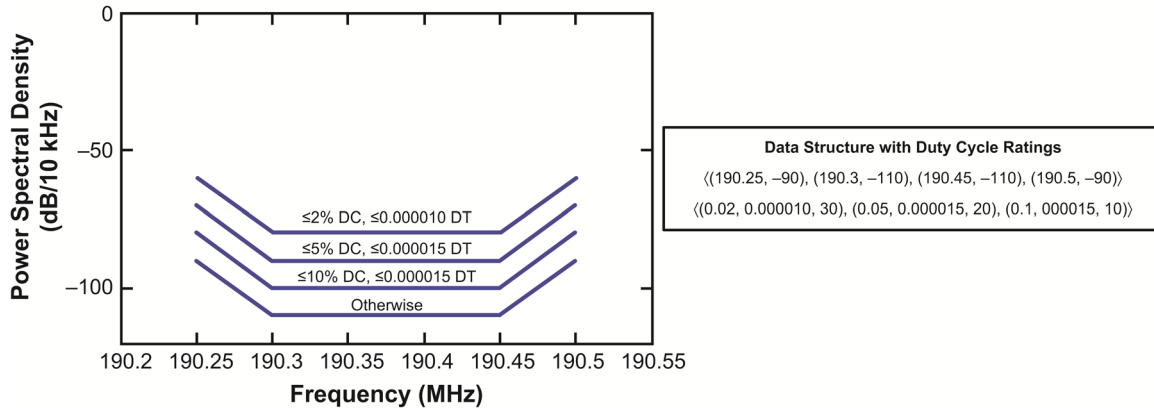


Figure 6—Using underlay masks to specify ratings for low duty cycle interference¹⁴

The HopRated type underlay mask allows modelers to describe frequency hop systems that tolerate the loss of some number of their hops to interference. The SCMMask in the UnderlayMask construct shall be a relative mask and the HoppingData in the HopRated structure defines how that mask moves in frequency and the time it dwells at each hop. This is the same as used in defining spectrum masks with the same meanings concerning spectrum occupancy, see 8.3.2. The ToleranceThreshold element describes the tolerable fraction of hops that can suffer interference. The optional HopDensity element may be used when the HoppingData identifies the hopping frequencies using band lists to override the constant HOP_DENSITY (see 3.4) in the computation of the fraction of hops that suffer interference in the presence of a frequency hopping transmitter which also specifies its frequency hopping using band lists, see 10.6.2.6.3.

The last type of rating for masks is one associated with a policy or protocol. In modeling, a mask is defined and an index number in the mask data that associates it with a particular policy or protocol modeled using the SCMPolicyOrProtocol construct, see 8.12.

Unrated masks using the TotalPower power margin computation method may also provide a value for SignalQuantity to override the SIGNAL_QUANTITY constant that specifies the number of representative signals to use in computing average interference from an interfering frequency hopping signal when the frequencies of hopping are specified in a band list, see 10.6.2.6.1.

Only unrated underlay masks may be given a confidence value. Rated underlay masks already capture the effects of different levels of interference for their rating. A collection of unrated underlay masks with confidence values indicates the distribution of interference that a receiver can tolerate. A model may have a single group of unrated underlay masks given confidence values for when LeastConstraining is present and when it is not.

Table 12 lists the data elements in the UnderlayMask construct. All masks have the mask itself, SCMMask, a resolution bandwidth, ResolutionBW, and the power margin computation method,

¹⁴ Frequencies of these masks are relative in the actual mask construct. So rather than 190.25 MHz, 190.3 MHz, 190.45 MHz, and 190.5 MHz for the control point frequencies, the mask definition would start with a reference frequency then the relative difference in frequency in each control point. As an example, in the case *RefFrequency* = 190.375 MHz and the values in the control points are -0.125 MHz, -0.075 MHz, 0.075 MHz, and 0.125 MHz.

MaskPowerMarginMethod. The Rating element is added when the underlay mask has ratings for either frequency hopping, low duty cycle or for a policy or protocol behavior. Table 13 list the data element of this structure. There are three possible types of ratings, only one is used. The DCRatedList is a data structure that provides a list of the duty cycle ratings. Each rating in the list includes the three-tuple of a duty cycle, maximum dwell time, and power level adjustment. Table 14 defines this type of list and the data elements used for each duty cycle rating in the list. Finally, there is the PorPIndex which is an integer that allows an underlay mask to be matched with a SCMPolicyOrProtocol construct in the receiver model. The matching instance of the SCMPolicyOrProtocol construct has the same index value.

Table 12—SCM underlay mask construct

Data element	Sub-elements	Types	Enumerated values/ unit of measure	Occurrences	Notes
Underlay Mask	—	Structure	—	—	—
	Rating	Structure	—	0..1	If used, indicates the mask is rated for conditions. Sub-elements in Table 13.
	ResolutionBW	Number	Megahertz (MHz)	1	The RBW of the mask indicating the bandwidth across which the indicated power is disbursed.
	SCMMask	Structure	—	1	An underlay mask. See Table 6.
	MaskPowerMargin Method	String/ Attribute	TOTAL_POWER, MAXIMUM_POWER DENSITY	1	Method used to compute compatibility
	Noise	Number	Decibel watt (dBW)	0..1	—
	SINR	Number	Decibel (dB)	0..1	—
	I2NRatio	Number	Decibel (dB)	0..1	—
	I2SRatio	Number	Decibel (dB)	0..1	—
	SignalQuantity	Integer	—	0..1	Optional override of the SIGNAL_QUANTITY constant and ≥ 3 when used.
	Independent	Boolean	—	0..1	Indicates whether interference computations with the mask contributes to aggregate effects. Use indicates it does not. Assumed FALSE when not used indicating it does.
	LeastConstraining	Boolean	—	0..1	When present, it indicates that the mask is intended for use in a least constraining point interference computation (see 10.12). Otherwise, when not present use a most constraining point computation (see 10.11).
	Confidence	Structure	—	0..1	Used in a model with multiple masks showing a distribution of allowed interference. See Table 3 for the data description.

Table 13—SCM underlay mask rating data

Data element	Sub-elements	Types	Enumerated values/ unit of measure	Occurrences	Notes
Rating	—	Structure	—	—	Choose of one of the following:
	DCRatedList	Structure	—	1	List of adjustments to the relative level of a mask based on cumulative duty cycle of the interferers. Sub-elements in Table 14.
	HopRated	Structure	—	1	Describes how the mask moves in frequency. Replaces RefFrequency in SCMMask. Used with total power method only. Sub-elements in Table 15.
	PorPIndex	Integer	—	1	Used to associate the mask with an SCMPolicyOrProtocol Construct.

Table 14—SCM duty-cycle-rated list and rating adjustments

Data element	Sub-elements	Types	Enumerated values/ unit of measure	Occurrences	Notes
DCRatedList	—	Structure	—	—	—
	DCRating	Structure	—	1..n	—
DCRating	—	Structure	—	—	—
	DC	Number	—	1	Fraction of time interferers are transmitting
	MaxDwellTime	Number	Seconds	1	Maximum duration of a contiguous transmission
	Adjustment	Number	Decibel (dB)	1	Relative power adjustment of the mask

Table 15—SCM underlay mask hop rating adjustment

Data element	Sub-elements	Types	Enumerated values/ unit of measure	Occurrences	Notes
HopRated	—	Structure	—	—	—
	HoppingData	Structure	—	1	Sub-elements in Table 9.
	HopDensity	Integer	—	0..1	Override value for HOP_DENSITY. Only used with HoppingData that uses BandList. ≥3.
	ToleranceThreshold	Number	—	1	Fraction of hops in which the interference threshold may be violated.

8.4.3 Modeling requirement

The main role of the underlay mask is to identify the spectral and small-scale temporal limits to interference. The underlay mask directly interacts with the spectrum masks of interfering signals. Determining whether a transmitted signal interferes with a receiver requires use of multiple constructs to perform a link budget assessment. The interaction between an underlay mask and a spectrum mask provides a power margin indicating the attenuation necessary through the other constructs to achieve their spectrum use compatibility. The computation of this power margin is described in 10.6. There are two methods to compute the margin, the total power method and the maximum power density method. The modeler of the underlay mask specifies the method that is used with each modeled mask. The link budget computations and the determination of compatibility between models are described in Clause 10 and Clause 11. Modelers build underlay masks with the understanding of how the models will be used to compute compatibility. The methods in Clause 10 and Clause 11 are very important not only to understand the specific meaning of underlay masks but also to understand how to build underlay masks.

Modelers may model a receiver with multiple underlay masks to reveal that the receiver is more tolerant to particular types of interference. The power margin of the system is computed using the least restrictive underlay mask for which the interfering transmitter model meets all the use criteria of the underlay mask. When a modeler uses multiple underlay masks for a receiver, there shall still be one general mask that would cover all potential types of interference from transmitter models that cannot meet the specialized criteria of any of the other underlay masks of the receiver model.

Although receiver models may use multiple underlay masks to capture their performance, some combinations of underlay masks may result in conflicting approaches to computing interference, especially aggregate interference. The following restrictions seek to eliminate these conflicts and any ambiguity in computing compatibility.

- a) Every receiver model shall have an underlay mask that serves as the default mask. Only an unrated mask or a frequency hopping mask may serve as that mask.
- b) A hop rated underlay mask shall not be combined with any other type of mask unless the mask is independent. Hop rated masks may be combined with other hop rated masks.
- c) A receiver model shall not mix mask power margin methods where some portion of its underlay masks use the total power method and another portion use the maximum power density method unless all the underlay masks of one of those portions are each identified as independent.
- d) A receiver model may provide multiple unrated underlay masks; however, aggregate interference shall only be accumulated against individual masks and not added across masks.
- e) A receiver model may provide multiple DC rated masks; however, the effects of multiple pulsed signals shall be assessed first to arrive at the DC rating of their combined effects before a DC rated mask is selected for accumulating their aggregate interference.
- f) Confidence shall only be used with unrated underlay masks and when used the receiver model shall not provide any additional masks, rated or otherwise, unless they are independent. If the modeling goal is to associate multiple underlay masks to the same confidence level, then use multiple receiver models each with the appropriate collection of underlay masks and assign the confidence to the receiver model.

Additionally, it is good modeling when attempting to capture the cumulative confidences that result from bit error rates associated with different SINR levels to use multiple confidence rated reference power levels as opposed to using multiple confidence rated underlay masks.

Broadcast transmitter models may optionally provide a spectrum-mask-referenced underlay mask to indicate the receiver model for the broadcast. When a spectrum mask reference underlay mask is used in a broadcaster transmitter model, that model shall also have a MinimumPSFD construct. If confidence is used in the reference power of model, then the lowest power level shall be used to scale the underlay mask. The role of this construct in the model is to define the limits of protection to these receivers. Subclause 8.11 describes this construct and give greater detail on its role.

8.5 Power map

8.5.1 Purpose and use

The power map captures the effects of antenna gain, insertion losses to the antenna, the polarization mismatch loss, and the effects on gain that are the result of the near range environment (e.g., the reflective effects and blockages that result from the surfaces and protrusions of the platform on which the antenna is mounted or the effects of structures that are nearby). The power map provides an approach to define these values directionally.

The power map together with reference power, the propagation map, and a spectrum mask define PSFD as a function of direction and distance from a transmitting antenna. The same combination, except using an underlay mask in lieu of a spectrum mask, in a receiver model conveys the threshold power spectral flux density by direction that individually results in interference at the receiver.

Power maps can capture the effects of polarization on the strength of received signals. The polarization of the transmitter may be specified, and an appropriate loss may be specified at the receiving antenna based on the polarization mismatch with the transmitting antenna.

Antennas have a large role in determining the compatibility of systems. Many systems have dynamically changing antenna characteristics including radars where antennas scan and track, cellular system which use directionality to spatially multiplex signals, and smart antennas in communications systems that attempt to optimize reception of a desired signal in the presence of interfering transmitters by dynamically steering either beams or nulls. These antennas may mitigate the occurrence of interference with external systems; however, their effectiveness depends largely on the scenario of use and the behaviors of the antennas. Not all these behaviors can be modeled in a power map. Power maps provide methods to capture the more deliberate behaviors such as scanning and tracking but at best can assign a probability to the success of adaptation. In cases where particular pairs of systems are known to be compatible based on the adaptation methods used, the SCMPolicyOrProtocol construct is the more applicable means to capture that compatibility in a model.

The intent of the SCM is to capture the geospatial limit of a use of spectrum. So, constraints to transmit power are defined as the effective PSFD at a frequency at a specified distance away from the antenna rather than the power driving an antenna. Transmitters with high gain antennas shall still conform to the PSFD constraints. Authorization models use the combination of a SCMPowerMap, ReferencePower, and SpectrumMask constructs to define the allowed PSFD after the antenna. These may not exactly match those of the devices being given the authorization. The expectation is that the system given the authorization will choose the operating settings that achieve a PSFD after the antenna within the guidance of the authorization.

8.5.2 Data elements and their meaning

8.5.2.1 General

The SCM power map has six elements, an orientation, a scanning region, a gain map, a polarization, a location index, and a confidence. The required elements are the orientation and gain map. The orientation specifies the reference coordinate system for the gain map and the gain map uses the SCM map approach described in 7.3 for specifying directional power flux density (PFD). The optional scanning region also uses the SCM map but there are only two directional values, 1 and 0, where 1 identifies in what directions the z-direction (elevation = -90°) of the gain map is scanned. When a scanning region is part of the model, the orientation defines the scanning region map orientation. The polarization identifies differences in gain to assess when transmitter antenna and receiver antenna polarizations match or mismatch. The location index allows the modeler to create multiple power maps and assign them to different locations of the model. The Confidence element allows the modeler to identify the probability that one of multiple power maps is used at