



IEEE Recommended Practice for the Analysis of In-Band and Adjacent Band Interference and Coexistence Between Radio Systems

IEEE Communications Society

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

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and

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Dynamic Spectrum Access Networks**

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Abstract: Technical guidelines are provided in this recommended practice for analyzing the coexistence or, alternatively, the interference between radio systems, operating in the same spectrum assignment or between different spectrum assignments.

Keywords: adaptive radio, coexistence, cognitive radio, dynamic spectrum access, interference, policy-defined radio, software-defined radio, spectrum, spectrum access

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Introduction

This introduction is not part of IEEE Std 1900.2-2008, IEEE Recommended Practice for the Analysis of In-Band and Adjacent Band Interference and Coexistence Between Radio Systems.

Introduction to IEEE SCC 41 and the IEEE 1900 series of standards

This recommended practice was developed under the auspices of IEEE Standards Coordinating Committee 41 (Dynamic Spectrum Access Networks, or DySPAN) (formerly IEEE 1900 Standards Committee on Next Generation Radio and Spectrum Management). SCC 41 (DySPAN) serves as a forum for the exchange of information in the area of dynamic spectrum access networks and to act as a sponsor for related standards projects. Taken together, current and future activities under the SCC 41 (DySPAN) will provide standards and recommended practices for addressing the many facets and issues introduced by DySPAN. Individual standards activities are designated as a series of p1900.x projects and include:

- Recommended practice for interference and coexistence analysis (this recommended practice)
- Recommended practice for dependability and conformance evaluation of regulatory compliance for radio systems with dynamic spectrum access
- Standard architectural building blocks enabling distributed decision making for optimized radio resource usage in heterogeneous wireless access networks
- Standard terms, definitions, and concepts for advanced radio spectrum management
- Other topics to be determined

Use and interpretation of this recommended practice (prepared by the IEEE P1900.2 Working Group) is expected to be aided and facilitated by referring to the products of the other, complementary projects under SCC 41 (DySPAN), as they are completed and published.

Introduction to IEEE Std 1900.2

Perhaps the critical question to be answered when analyzing interference is, at what point is there harmful interference among radio systems coexisting in common spectrum assignments? As it is commonly used, harmful interference is a broad concept, combining the physical facts of a situation with the economic perspective and values of the stakeholders involved. This document seeks to bring greater understanding and precision to the term and to apply more objective criteria to its assessment, particularly in a dynamic and changing coexistence environment.^a This recommended practice addresses several elements necessary for making an analysis of the potential for harmful interference. It seeks, wherever possible, to require a scientific and objective approach for an interference and coexistence analysis. It is hoped that by stating and clarifying assumptions and by providing a normalized structure for engineering analysis that the determination of the relative importance of the benefits and risks will be facilitated.

^aThe imprecise nature of the concept is best addressed by first determining the facts, differing assumptions that might be made, and then allowing the relevant decision-making authority to make its decision within the range of credible conclusions. This standard primarily serves to identify the agreed on facts and to propose thresholds and objective criteria for a specific scenario. In the International Radio Regulations (see IRR, Appendix 5 [B18]), and relevant ITU-R recommendations, the terms “harmful,” “permissible,” and “accepted interference” are defined, demonstrating the consensus of that body that levels of interference exist that are acceptable under conditions of static spectrum assignment. (See the international radio regulations of the ITU-R 1.166, ITU-R 1.167, ITU-R 1.168, and ITU-R 1.169.) This standard is intended to extend to spectrum assignments that may change dynamically, perhaps rapidly in time, depending on traffic or other local conditions, among a number of radio systems, coexisting in a common spectrum assignment.

Stated simply, an interference and coexistence analysis involves answering questions, such as:

- Where am I?
- Who else is around me?
- What do I have to worry about?
- What are my rights and responsibilities relative to others?
- What can help us get along?

This recommended practice provides a structure and describes a method for analyzing the interference between radio services under a variety of coexistence scenarios. Many variables to be used in this analysis will be detailed. The annexes provide helpful supportive material and examples of analysis using this document.

One reason for the analytical structure specified in this document is to provide an objective and uniform framework for assessing and analyzing interference and coexistence. From this framework, an understanding is gained of assumptions, dependencies, and relative importance of the variables of the problem.

In the end, a thorough interference and coexistence analysis provides an invaluable support when considering the acceptance of new technologies or systems that are to coexist in common, shared spectrum assignments.

Having this understanding of the physical reality and the technical facts, economic analysis or even a political formulation may be more effectively applied. To use the vernacular, you can figure out who pays whom and how much to make life good. Companies can also anticipate customer satisfaction and warranty costs for products that will be coexisting in dynamically assigned spectrum assignments.

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1. Overview

1.1 Relationship to traditional spectrum management

The introduction to the 2005 edition of the ITU-R National Spectrum Management Handbook states:

Society’s increasing use of radio-based technologies, and the tremendous opportunities for social development that these technologies provide, highlight the importance of radio-frequency spectrum and national spectrum management processes. Technological progress has continually opened doors to a variety of new spectrum applications that have spurred greater interest in, and demand for, the limited spectrum resource. Increased demand requires that spectrum be used efficiently and that effective spectrum management processes be implemented. In this framework, modern data handling capabilities and engineering analysis are important to accommodate the variety of potential users seeking access to the spectrum.

Radio communications is heavily used in a growing number of services such as national defense, public safety, broadcasting, business and industrial communications, aeronautical and maritime radio communications, navigation, and personal communications. Radio communication links, as opposed to wireless telecommunications, are necessary in a dynamic or mobile environment, where wire-line telecommunication may not be available, or where telecommunications have been disrupted, such as in emergency or natural disaster situations. Radio communication systems may operate from satellites or from terrestrial platforms.

If the spectrum is to be used efficiently, its use must be coordinated and regulated through both national regulations and the Radio Regulations of the International Telecommunication Union

(ITU). The ability of each country to take full advantage of the spectrum resource depends heavily on spectrum management activities that facilitate the implementation of radio systems and ensure minimum interference. To this end, administrations should, as appropriate, make use of computerized spectrum management systems.

The demand for spectrum continues to increase dramatically, and with it, the importance of efficient spectrum management is increasing. Fixed, universal rules to coordinate spectrum are not efficient. The most efficient spectrum allocation is not fixed to a single set of rules for all locations and situations nor is it static over time. Optimally spectrum management would be adaptive to specific situations and variable to the specific conditions at a given time and place. Dynamic and adaptive management of spectrum is now possible. The development of computer science, radio engineering, and related disciplines has reached the point where spectrum usage can now be controlled automatically by coexisting radio systems in real time. This replaces the manual method in which human radio-frequency (RF) planners used static frequency assignments.

1.2 Introduction to this recommended practice

Interference between systems occurs when operation of one system affects the performance of another system.¹ Two or more radio systems successfully coexist when the level of performance of all systems is judged to be acceptable. There may be some interference, but it is generally judged to be within acceptable limits.

Emerging technologies such as cognitive radio, ad hoc wireless networks, as well as dynamic and adaptive systems complicate the interference and coexistence analysis. For example, if a network can reroute data so loss of a particular link has no impact on end-to-end user performance, does loss of that link constitute interference? If it is judged to be interference, does it constitute harmful interference? If so, what is the appropriate remedy?

This recommended practice provides a structure for interference and coexistence analysis. The purpose of providing such a structure is to guide the analyst in considering all relevant issues in a systematic way. Furthermore, a uniform structure makes the comparison of different analyses easier. When different analyses utilize a common structure and method of analysis the reasons for similarities or differences in conclusions are more quickly identified. Thus, focus may be brought to the critical elements, where more data or further analysis may either confirm results or aid in the understanding of differing conclusions.

1.3 Scope

1.3.1 Formal scope²

This recommended practice will provide technical guidelines for analyzing the potential for coexistence or in contrast interference between radio systems operating in the same frequency band or between different frequency bands.

1.3.2 Discussion of scope

This is a recommended practice for analyzing the interference and coexistence among radio systems. It establishes a structured framework for analyzing interference and coexistence. It also establishes a structured document format for presenting the analysis to others.

¹Although the focus of this standard is interference and coexistence of radio systems, other kinds of systems utilize spectrum and are dependent on spectrum for their operation. The analytical methods proposed in this standard may be used when analyzing scenarios, including spectrum-dependent systems other than radio systems.

²The formal scope is the scope approved in the Project Authorization Request for this project.

This recommended practice does not establish interference criteria. It does not propose judgments on what constitutes interference or on what constitutes harmful interference. It does, however, indicate a number of effects and conditions that should be considered to provide a complete interference and coexistence analysis.

Subclause 5.3 of this recommended practice outlines the report section and subsection³ headings for a report of a recommended analysis of interference and coexistence. This may be used as the framework for a report complying with this recommended practice.

Annex D through Annex G provide sample analyses, in accordance with the structure and method of this recommended practice.

1.4 Purpose

1.4.1 Formal purpose⁴

New concepts and technologies are rapidly emerging in the fields of spectrum management, policy-defined radio, adaptive radio, and software-defined radio. A primary goal of these initiatives is to improve spectral efficiency. This recommended practice will provide guidance for the analysis of coexistence and interference between various radio services.

1.4.2 Discussion of purpose

By standardizing the framework and documentation structure for interference and coexistence analysis, this recommended practice enables side-by-side comparisons of the analyses presented by various parties. It thereby may streamline the process of determining whether interference and harmful interference have or will occur. Furthermore, this document provides a framework within which differing analysis can be understood, considered, and resolved.

In the case of any particular standardized radio systems that may coexist or interact with others dynamically, it may be desirable to develop standard interference and coexistence criteria. The structured framework described in this document should be used by the authors of such standards. However, this recommended practice does not state or attempt to define any particular interference or coexistence criteria.

1.5 Rationale

A reader may ask why this recommended practice was created. This recommended practice has been developed in response to the emergence of new radio technologies and changes in spectrum policy and regulation. Changes in regulations have the potential to enable flexibility in services, radio access technology, and spectrum assignments. Together these changes have the potential to significantly improve spectral efficiency and communications performance through exploiting:

- Flexibility
- Dynamic, autonomous, and adaptive behavior
- Awareness, cognition, and intelligence
- Networking

³In this document, clause and subclause refer to portions of this document. Section and subsection refer to portions of an analysis report, prepared in compliance with this recommended practice.

⁴The formal purpose is the purpose approved in the Project Authorization Request for this project.

— Coexistence and sharing of radio resources

However, present spectrum management practices do not provide effective techniques for identifying interference among these types of advanced radio devices or for managing their access to the radio spectrum dynamically. This may create barriers to the introduction of these new radio technologies. At the same time, premature standardization of fixed interference criteria could also stifle innovation, since the sophisticated, complex behaviors of future environmentally aware and cooperative radio systems and services will continue to develop over time.

The application of the techniques outlined in this recommended practice will facilitate the continuing deployment of advanced radio technologies and thereby improvement in spectral efficiency and communications system performance.

Questions of interference may arise regarding actual or proposed radio systems. Normally there is a two-step process to understand and answer these questions. First, there is a technical debate to determine whether interference has occurred or will occur. Second, there is a broader, more general debate over what constitutes an acceptable level of interference, which includes issues such as regulatory history, public policy, and economic tradeoffs. The second debate often seeks to determine whether the interference, determined in the first debate, rises to the level of harmful interference or if system effects on coexisting systems require corrective action.

The process can be highly contentious. In the technical debate over interference, it often emerges that the differing conclusions of disputing parties derive from differing assumptions rather than from faulty analysis. When controversy arises, analysts will typically differ in one or more of the following areas:

- What scenarios and use cases should be assumed?
- What should be considered an interference event?
- What constitutes harmful interference?
- Who owns the margin?⁵

When differing viewpoints are anticipated, the analyst should take care to treat these questions with particular care. In the broader debate over whether interference is harmful, it often emerges that the disputing parties have different and incompatible definitions of harm. Merely determining the points on which the parties agree and disagree can require substantial investigation. Therefore, using a common structure and clearly identifying assumptions greatly assists in guiding discussion to the critical issues.

A well-prepared analysis answers the following questions:

- Why is this analysis being done?
- What are the questions being addressed?
- What need is being served?

If the possibility of significant misunderstanding exists about the scope of an analysis, the analysis report should clearly define areas that are being considered and, also, those areas beyond its scope.

⁵Margin is used here generically to refer to any of a number of buffers that exist to allow some protection to the desired level of operation. Various margins are maintained to allow products to vary, for example due to manufacturing variation, the influence of temperature, or other environmental factors. Providing some margin or buffer is necessary, if a desired level of service or reliability is to be provided, over a foreseeable but uncontrollable set of variables. Some examples of the types of margin that are discussed at various places in this recommended practice are design margin, operating margin, interference margin, safety margin, system margin, protection margin, fading margin, and reliability margin. Although each of these margins defines a different quantity, all of them serve to allow variation to not unduly influence some desired requirement.

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.

ANSI C63.14-1998, American National Standard Dictionary for Electromagnetic Compatibility (EMC), Electromagnetic Pulse (EMP), and Electrostatic Discharge (ESD) (Dictionary of EMC/EMP/ESD Terms and Definitions).⁶

ITU-R Handbook on National Spectrum Management, 2005 edition.⁷

NIST Technical Note 1297, Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results, Sept. 1994.⁸

3. Definitions, acronyms, and abbreviations

3.1 Definitions

For the purposes of this document, the following terms and definitions apply. The glossary in Annex H and *The Authoritative Dictionary of IEEE Standards Terms* [B12] should be referenced for terms not defined in this clause.

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

3.1.2 co-channel: The condition that exists when one transmitter operates in the same channel as a second transmitter.⁹

3.1.3 coexistence: The ability of two or more spectrum-dependent devices or networks to operate without harmful interference.

3.1.4 cognitive radio/cognitive radio node: (A) A type of radio in which communication systems are aware of their environment and internal state and can make decisions about their radio operating behavior based on that information and predefined objectives. The environmental information may or may not include location information related to communication systems. **(B)** Cognitive radio [as defined in **(A)**] that uses software-defined radio, adaptive radio, and other technologies to automatically adjust its behavior or operations to achieve desired objectives

3.1.5 cooperative (device or system): Devices or systems that can coordinate their use of spectrum.

⁶ANSI publications are available from the Sales Department, American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, NY 10036, USA (<http://www.ansi.org/>).

⁷ITU-R publications are available from the International Telecommunications Union, Place des Nations, 1211 Geneva 20, Switzerland (<http://www.itu.in/>).

⁸For information on how to purchase FCC and NIST publications, contact the Superintendent of Documents, US Government Printing Office, Washington, DC 20402 USA.

⁹In frequency bands that do not have fixed channel allocations, a determination must be made as to how much overlap constitutes a co-channel situation and alternately when two signals are operating in adjacent channels.

3.1.6 dynamic spectrum management: A system of spectrum management that dynamically adapts the use of spectrum in response to information about the use of that spectrum by its own nodes and other spectrum-dependent systems.

3.1.7 electromagnetic compatibility: The condition that prevails when devices or networks perform their individually designed function in a common electromagnetic environment without causing or suffering unacceptable degradation due to electromagnetic interference to or from other equipment in the same environment.

3.1.8 interference event: A circumstance in which a quantified threshold level of interference has been exceeded. Interference events are specified in terms of the relevant variables for a specific scenario, e.g., time, frequency, amplitude, and performance metrics.

3.1.9 noncooperative (device or system): Devices or systems that operate independently of a source device or system with regard to the use of spectrum.

3.1.10 recipient device: A device being analyzed as to its potential for receiving interference from a source device or system.

NOTE—An analysis seeks to determine the level of impact on these devices. The protection need not be a legal requirement but may arise from ethical or social concerns.

3.1.11 recipient system: A system being analyzed as to its potential for receiving interference from a source device or system.

NOTE—An analysis of a recipient system will often study the potential for system impact and may build on an analysis of the potential for interference to individual devices in the system.

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

3.1.13 software-defined radio (SDR): **(A)** (Normative) A type of radio in which some or all of the physical layer functions are software defined. **(B)** (Informative) U.S. Federal Communications Commission Definition [1]: A radio that includes a transmitter in which the operating parameters of frequency range, modulation type or maximum output power (either radiated or conducted), or the circumstances under which the transmitter operates in accordance with Commission rules, can be altered by making a change in software without making any changes to hardware components that affect the radio frequency emissions. **(C)** (Informative) ITU-R Definition (including the notes) [2] [3]: A radio in which RF operating parameters including but not limited to frequency range, modulation type, or output power can be set or altered by software, and/or the technique by which this is achieved.

NOTE 1—Excludes changes to operating parameters that occur during the normal preinstalled and predetermined operation of a radio according to a system specification or standard.

NOTE 2—SDR is an implementation technique applicable to many radio technologies and standards.

NOTE 3—Within the mobile service, SDR techniques are applicable to both transmitters and receivers.

3.1.14 source device: A device being analyzed as to its potential for interference to recipient devices or systems.

NOTE—In some previous documents in the field, these devices were called secondary devices.

3.1.15 source system: A system being analyzed as to its potential for interference to recipient devices or systems.

NOTE—An analysis of a source system will often focus on the combinatorial effects of the source devices that compose the system and will build on an analysis of the potential for interference from the individual source devices in the system.

3.1.16 spectrum utilization: The spectral space denied to other potential users.

3.2 Acronyms and abbreviations

AM	amplitude modulation
ANSI	American National Standards Institute
AREPS	Advanced Refractive Effects Prediction System
ATSC	Advanced Television Systems Committee
CDF	cumulative distribution function
CDMA	code division multiple access
CFR	Code of Federal Regulations
C/I	carrier-to-interference
CW	carrier wave
dB	decibel
dB SPL	decibels referenced to a sound pressure level of 20 μ Pa
dBm0	power level in dBm relative to zero transmission level point
DSA	dynamic spectrum access
DTV	digital television
DTX	discontinuous transmission
E3	electromagnetic environmental effects
EMC	electromagnetic compatibility
ETSI	European Telecommunications Standards Institute
<i>f</i>	frequency
FDD	frequency division duplex
FDP	fractional degradation of performance
GSM	Global System for Mobile
HFA	High-frequency average
iDEN	Integrated Digital Enhanced Network
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
ISO	International Organization for Standardization
JTC	Joint Technical Committee
LOS	line of sight
MIMO	multiple in multiple out
N	noise
NADC	North American Digital Cellular
OLOS	obstructed line of sight
OSI	open systems interconnection
P	transmit power or forward power (Watts)
PAR	peak-to-average ratio
PC	personal computer
PCS	personal communications services
PEP	peak envelope power
P-MP	point to multipoint
Q	quality factor
QAM	quadrature amplitude modulation
RBW	resolution bandwidth
RF	radio frequency
RMS	root mean square
RSE	relative spectrum efficiency

Rx	receiver
SDR	software-defined radio
S/N	signal-to-noise ratio
SPE	standard parabolic equation
SPL	sound pressure level
SUE	spectrum utilization efficiency
TDMA	time division multiple access
TDD	time division duplex
TV	television
Tx	transmitter
UARFCN	UTRA absolute radio frequency channel
UKAS	United Kingdom Accreditation Service
UMTS	Universal Mobile Telecommunications System
UTRA	Universal Terrestrial Radio Access
VoIP	Voice over Internet Protocol
WAPE	wide-angle parabolic equation

4. Key concepts

4.1 Interference and coexistence analysis

This document provides a method for performing an interference and coexistence analysis. An interference analysis and coexistence analysis are complementary and related concepts.

An interference analysis starts with energy introduced by a source system and studies the effect of that energy from the most basic physical layer through higher levels until the impact of that energy on recipient systems is understood. A coexistence analysis starts at the system level, and studies the ability of a recipient system to communicate or accomplish its intended useful effect in the presence of interference introduced by a source system. A coexistence analysis is focused on system level performance issues, seeking a comprehensive understanding of benefits and impacts of coexistence, including an understanding of mitigations of interference and the user behavior.

The differing approach of an interference analysis, in contrast to a coexistence analysis, is useful in assuring that a case is completely understood. Starting from the energy introduced by the source is most helpful in identifying all the potential impacts. A focus on system performance and moving down toward the impact of energy is often more helpful in giving a meaningful context to the impact of that energy.

4.2 Measurement event

A measurement event defines the basic quantities measured in order to analyze the interference or coexistence. A measurement event is a single instance of a sample to be used to characterize the state of interference. It is a data sample, measured or calculated, using a specified set of parameters. In some cases, the measurement event may capture multiple variables or the same variable from multiple devices at the same time and contain their values. Therefore, a measurement event may contain multiple values. The measurement sample is selected to provide a context for interference events. A measurement event may be as simple as the average power received from a source over an interval of time. However, no matter how simple or complex, it must be well defined by radio system variables, such as the frequency bandwidth, averaging time, or other system variables, such as a time period during which a specified quality of service will be measured.

4.3 Interference event

An interference event is a measurement event in which a source device or system has a quantifiable performance effect on the recipient device or system or for the user of a recipient device or system. The concept of an interference event is used in the analysis for determining the amount and severity of interference. Interference events are therefore a subset of the measurement events. An interference event is scenario dependent. Depending on the service, performance degradation can be manifested in many ways. For example, as lower data throughput, lower voice quality, video distortions, decreased battery life, increased incidence of blocked or dropped links, delay, reduced system capacity, reduced interference margin, or reduced capability of the recipient system to adapt to new conditions or advance with new technology. An individual interference event may not in itself be deemed harmful. The definition of when interference events degrade performance to an unacceptable level is termed, harmful interference, and is dealt with when defining the criteria for harmful interference for an analysis.

4.4 Harmful interference

Harmful interference is the level at which the analysis deems interference events have created unacceptable interference. The level shall be defined in terms of interference events across time and/or users or systems that cause an unacceptable degradation of the recipient system's performance, in the judgment of the analyst. This threshold will be used when determining whether harmful interference has occurred. The analysis of a system may involve more than one threshold. The analysis shall state the reasons for selecting the harmful interference criteria used in the analysis.

Determining when interference events become excessive is a difficult value judgment. It may be that different analyses are in general agreement except for specific thresholds defined in the criteria. The viewpoint of those connected with the recipient system often is different than those connected to the source system. When this is the case and the differing analyses use the structure proposed in this recommended practice, then the debate may be quickly focused on the critical points of difference. This facilitates the comparison of analyses, understanding differences in conclusions and recommendations and, ultimately, the decision-making process.

4.5 Physical and logical domains

Communication systems have often been described in terms of a physical layer and several higher layers. This document refers instead to the *physical domain* and the *logical domain*. The physical domain covers the transmission and reception of the radio signals, including power, antenna effects, noise, signal modulation, coding, interference, sensitivity, intended and unintended emissions, and radio performance. The logical domain covers all the behaviors of the higher OSI (Open Systems Interconnection) layers.¹⁰ Examples of issues that may attract significant interest are medium access control, packetization, retransmission, routing, scheduling, services, and system performance. System performance may include, for example, capacity, blocking, power consumption, link/system reliability, quality of service, and excess delay. The logical domain considers of other device and system behaviors that interact with the communication system, such as battery management algorithms and location-dependent control algorithms.

Interference analyses have traditionally focused on the physical domain. Such studies consider how the RF energy emitted by one system affects other systems. One major new aspect of interference and coexistence analysis raised by the new radio technologies is whether to broaden the scope of the traditional physical domain to also include the logical domain.

A canonical example of such a question was stated earlier in this introduction (see 1.2): *[I]f a network can reroute data so loss of a particular link has no impact on end-to-end user performance, does loss of that*

¹⁰ISO/IEC 7498-1:1994 [B17].

link constitute interference? In one view, no interference has occurred because no user experiences reduced performance. In another view, the rerouting capacity of the network represents a designed-in safety margin for tolerating a variety of effects such as link congestion and node mobility as well as against external interference. This safety margin is part of the user's expected performance. Degradation of that margin due to operation of another radio system reduces the statistically expected performance of the network going forward, and therefore, interference has occurred.

Such questions must be considered as part of an interference and coexistence analysis. However, these questions must often be answered on a case-by-case basis. This recommended practice is designed to permit physical and logical domain behaviors to be properly considered in analyzing an interference and coexistence scenario. The structured framework described in this recommended practice should be applied to both physical domain effects, to logical domain effects, or to both, considered together, as appropriate in a particular situation.

5. Structure of analysis and report

5.1 Structure for analysis

An interference and coexistence analysis considers the effects of one radio system (the *source device or system*) on the operation of one or more other radio systems (the *recipient device or system*).

The analytical framework adopted in this recommended practice consists of four cascaded, interdependent steps: scenario definition, establishment of interference and coexistence criteria for the recipient system, definition of variables or behaviors used in modeling, and the modeling, measurement or analysis itself.

Figure 1 depicts the analytical process and structure recommended by this recommended practice. The structured approach depicted in the figure is recommended to serve as both a logical, step-by-step procedure to be followed in conducting the analysis and an organization template for the documentation of the entire analysis. Clause 5 through Clause 10 provide guidance on the performance and documentation of each of these steps.

5.1.1 Scenario definition

The deployment, usage and architectures contemplated for the recipient and source systems are described in the scenario definition step. For example, the recipient system may be a broadcast service, for which there is a known, fixed transmitter configuration requiring protection of receive-only, independently-operated nodes, distributed across wide geographical areas around the transmitter with little or no capability to predict or measure precise receiver locations. The source may be a mobile ad-hoc network that has GPS to provide location information for each node.

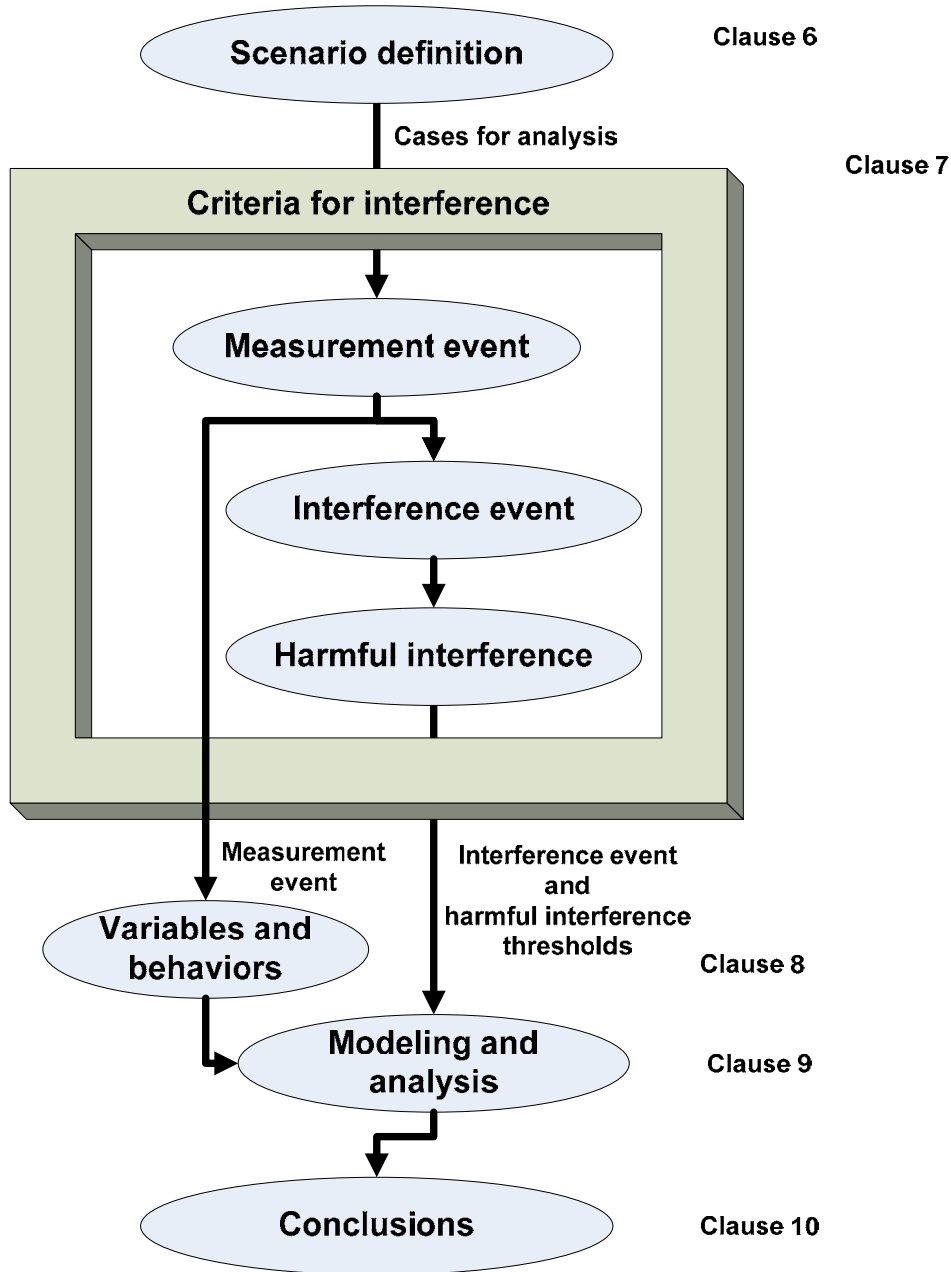


Figure 1 —Overview of the interference and coexistence analysis process

5.1.2 Establishment of interference and coexistence criteria

Interference and coexistence criteria for the subject system are established and described in this step. The goal is to provide realistic criteria for the defined scenario(s).

In some instances, purely physical domain, discrete criteria may be appropriate, such as the maximum interference power in a single link. For the broadcast service example, as just described in 5.1.1, the appropriate criteria may involve statistical analysis of a signal-to-interference ratio over a region. In other instances, more subtle criteria invoking logical domain variables may be established. These criteria may include effects such as dropped calls in a cellular network, reduced service quality, or reduction of overall throughput in an ad hoc digital communications network.

In this step, issues such as erosion of system margin or diminished system capacity are addressed. This recommended practice provides standard definitions and a categorization of these logical domain effects to assist in making clear and supportable arguments for what constitutes harmful interference.

5.1.3 Selection of relevant variables or behaviors

In this step, the variables or behaviors of the source or recipient systems that are relevant to the particular scenarios and interference criteria are selected for use in the analysis, modeling, measurement, or testing of the interference situation. The selected behaviors are defined precisely, such as by using pseudo-code or other algorithmic representation, to fully represent the systems' interactions and reactions to interference.

In many past analyses, purely physical domain variables have been considered in the models, simulations, or calculations. Such analyses only consider such variables as transmitter power, location, and frequency, as these are assumed to be the only key variables. Newer analyses, addressing new adaptive systems and spectrum-sharing concepts, also consider the logical domain behaviors. These analyses may include such issues as frequency abandonment algorithms, networked spectrum sensing information, or integration protocols. These logical domain variables may be dominant in determining the behavior of the systems and the coexistence outcome. For cases in which logical domain behavior is operating in either the source or the recipient systems, such variables should be considered.

5.1.4 Modeling, analysis, measurement, and testing

In this step of the analysis, the effects of the source(s) on the recipient(s) is modeled, analyzed, measured, or tested for appropriate ranges of the variables. From this analysis, a declaration is made based on the established criteria regarding whether harmful interference has occurred or will occur.

5.2 Process flow—divergence, reduction, and convergence

The analysis process is initially characterized by divergence. A study question may have many possible use cases. Each use case has multiple frequency relationships, and each frequency relationship potentially has many system relationships. The range of choices introduced at each step leads to a combinatorial growth in the number of cases.

Periodic reduction steps help bound the number of cases being advanced for treatment. A matrix reduction step may be introduced at any stage of the analytical process. When the important cases for analysis can be identified early in the process, this may allow several steps in the analysis to be combined. In other cases, it is necessary to identify explicitly multiple cases and to perform some part of the analysis before the more critical cases can be identified. It is critical that the important cases are identified, as there will typically be too many possibilities for an analysis to deal with all possible cases. An exhaustive analysis would require an extraordinary effort to accomplish.

At the end of an analysis, the cases are converged to a summary and conclusion of the findings. The convergence may be done in several steps or in a single, final step at the end of the analysis.

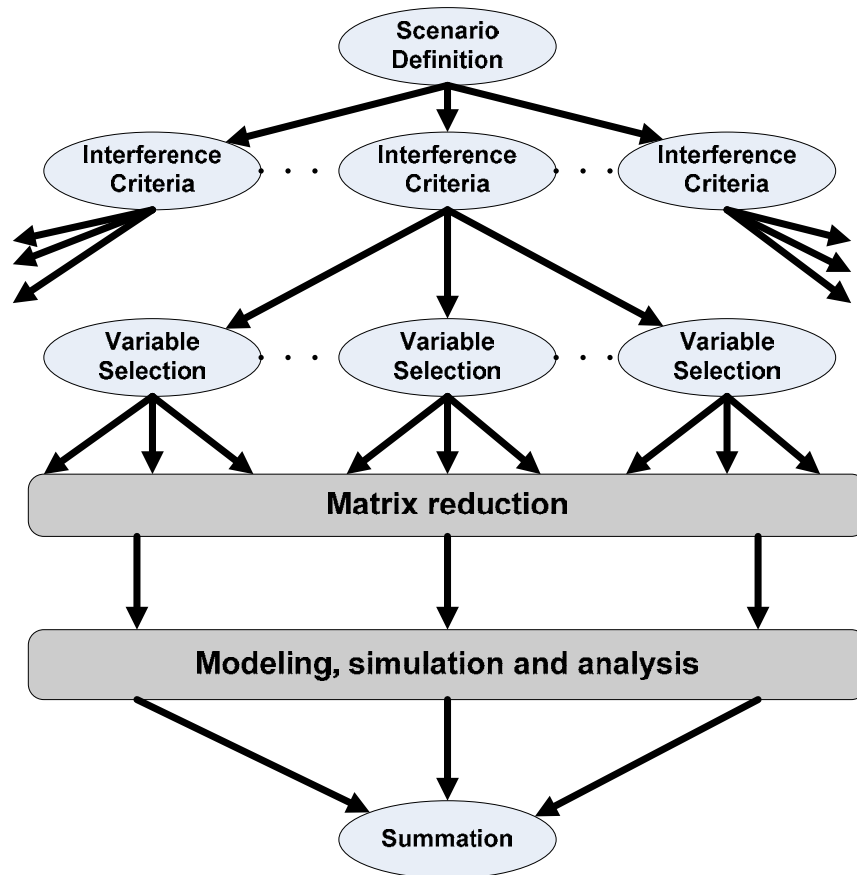


Figure 2 —An interference and coexistence analysis initially is characterized by successive stages of divergences with recursive reduction steps and concludes with converging and summarizing the findings.

Figure 2 illustrates an initial divergent characteristic of an interference and coexistence analysis followed by recursive reduction steps and concluding with convergence to a summary and conclusion.

All analyses begin with a study question. Many study questions might be applied in multiple scenarios, and so there is a divergence at this first step in the process. Each scenario or use model has multiple frequency relationships (e.g., in-band, low-frequency adjacent band, or high-frequency adjacent band). Each frequency relationship may have many system relationships. For example, many different types of incumbent systems may be currently operating in the proposed frequency band or in each adjacent band. It will be common to have a great many potential cases for analysis at the end of the scenario definition process. Matrix reduction steps during or at the end of this phase of the analysis will be a common occurrence to reduce the number of cases to a manageable level.

Looking further it will become clear that each system relationship may have multiple types of interference (e.g., audio interference, operational interruption, reduction of operating margin, and increased latency or jitter). Each type of analysis may be analyzed on more than one level (e.g., user perceptible interference, increased bit errors, carrier to interference ratio, and quality of service).

A full treatment of all possibilities will seldom be possible. Therefore, the matrix of possible cases may be reduced to a manageable number of critical cases for detailed analysis. The cases for detailed analysis are selected using some guiding logical process. In some cases, the defining or “corner cases” are selected, where it can be argued that when these are understood, all other cases are also understood. In other situations, the most critical cases may be selected, with the argument that other cases are of relatively minor concern. Other selection logic may be used but should be clearly stated and defensible if challenged.

At the end of the process, the findings are converged, sometimes in multiple steps, until a single summary and conclusion(s) can be proposed.

5.3 Report structure

5.3.1 Quick reference guide

Table 1 provides a “quick reference” of the report structure for an analysis, in tabular form. It was developed as a tool to assist analysts as they prepare their reports, following this recommended practice. A complete discussion of what should be contained in each section of the report is provided in the main body of this recommended practice.

NOTE—In this recommended practice, clause and subclause are used to refer to this document, whereas section and subsection are used to refer to portions of the report of an analysis developed following this recommended practice.

5.3.2 Introductory material

An executive summary section should be placed as the first section or near the first section of a report. The executive summary should provide a brief summary of the problem and the findings of the analysis. It should give the reader an understanding of the scope and purpose of the analysis performed, the major assumptions and decisions, the analysis, measurements or modeling performed, and a summary of the findings.

After the executive summary should be a section on findings, providing a top-level summary of findings. This provides a presentation of the core outcome(s) of the analysis. The full details and supporting data are placed in the body and the closing summary section of the analysis.

6. Scenario definition

6.1 General

This recommended practice recommends that an interference and coexistence analysis begin by describing its context. Why is this analysis being performed? What is being proposed that needs analysis? What are the underlying assumptions? What are the assumptions and focus areas being analyzed? By answering these and similar questions in the early part of an analysis, other analysts and the readers may quickly understand both what will be done and if the analysis addresses their issues of interest.

As depicted in Figure 3, the scenario definition, which described in this clause, delivers one or more, at times many, cases for analysis. Each case will look at the potential for interference from the source device(s) or system(s) in the proposal in a specific recipient situation. Each case for analysis is then delivered to succeeding steps in the analysis for determination of interference event(s), harmful interference criteria, variable identification, and finally modeling and analysis.

Table 1—Structure of an interference and coexistence analysis report

Report section	Clause	Description
I. Executive summary	5.3.2	Give a short overview of the analysis.
II. Findings	5.3.2	What is the conclusion of the analysis?
III. Scenario definition	6	
A. Study question	6.2	What is the question or proposal being analyzed?
B. Benefits and impacts of proposal	6.3	What are the benefits and impacts of this proposal?
C. Scenario(s) and usage model	6.4	Where and how might this proposal be applied?
1. Frequency relationships	6.4.1	What is the frequency context being considered?
2. Usage model	6.4.2	In what ways will the subject being studied be used?
3. Characteristics of usage model	6.4.3	What are the characteristics of the usage model(s)?
a. Spatial and power characteristics	6.4.3.1	How closely will devices be used in relationship to each other? What transmit power is allowed? What are the characteristics of the transmission waveform?
b. Temporal characteristics	6.4.3.2	How frequently will each device transmit? When transmitting, how long does it transmit? Is the transmission governed by a fixed frame period?
c. Frequency characteristics	6.4.3.3	What frequency band and bandwidth will be used?
d. Other orthogonal variables	6.4.3.4	Are there other variables that will separate transmissions, like coding, MIMO, or antenna polarization?
4. System relationships	6.4.4	
a. Systems considered	6.4.4.1	What systems share the same band? What systems operate in adjacent bands? What other equipment might be affected by the transmission?
b. Protection distance	6.4.4.2	What protection distance is required or assumed for this analysis?
c. Geographic area for analysis	6.4.4.3	What geographic area is being analyzed?
d. Impact of interference	6.4.4.4	If there is interference, what are the consequences?
e. Interference mitigation	6.4.4.5	If there is interference, what can be done about it?
f. Baseline	6.4.4.6	What interference already exists?
D. Case(s) for analysis	6.5	What specific case will be moved forward for further analysis?
IV. Criteria for interference	7	
A. Interference characteristics	7.2	What are the characteristics of the interference? What kind of interference is of concern?
1. Impacted level	7.2.1	At what level will the interference be measured, C/I, bit errors, user perception?
B. Measurement event	7.3	What parameters will define a measurement event?
C. Interference event	7.4	When does a measurement event become an interference event?
D. Harmful interference criteria	7.5	At what point do interference events become harmful interference?
V. Variables	8	
VI. Analysis: modeling, simulation, measurement and testing	9	Perform the modeling, simulation, or analysis.
A. Selection of the analysis approach	9.2	Provide an explanation for the approach selected.

B. Matrix reduction	9.3	Which cases need to be modeled, simulated, or analyzed?
C. Performing the analysis	9.4	This subsection contains the models, simulations, or description of the analysis applied, including models, simulations measurements, or testing for the cases selected.
D. Quantification of benefits and interference	9.5	Quantify the benefits and interference.
E. Analysis of mitigation options	9.6	What are the mitigation options?
F. Analysis uncertainty	9.7	What is the uncertainty of the analysis?
VII. Conclusion and summary	10	What is the conclusion of this analysis? Present the findings and summarize the results.
A. Benefits and impacts	10.1	Summarize the benefits and impacts.
B. Summation	10.2	Summarize the analysis.

6.2 Study question

The process starts with a clear statement of the question to be studied. This study question will often be in the form of a proposal. What new system, regulation, or operating policy is being proposed for analysis?

6.3 Benefits and impacts of proposal

If the analysis is being done to explore a proposed innovation, regulation, policy,¹¹ or new technology, a description of the anticipated benefits and impacts should be placed in this section of the report.

A description of the anticipated benefits and impacts from the innovation, regulation, policy, or technology under study should be included in this section of the report. The anticipated benefits and impacts may affect many different parties and affect them in different ways. The parties benefited and the parties impacted should be identified. This discussion is particularly important when the parties benefiting are different from those that are impacted.

The description in this subsection should summarize the more detailed discussion of the benefit and interference impact developed in 10.1. This report section should make as explicit as possible the tradeoff between benefits and impacts and provide the analyst the opportunity to state their assessment of the value and cost of the proposal.

6.4 Scenario(s) and usage model

The scenario(s) being analyzed are described in this report section. A scenario description shall include a description of the source device(s) and system(s); the recipient device(s) and system(s); how they will be used; as well as the system users and the environment in which they will operate. The usage model should be described in a general way. This description may address, for example, questions such as follows: Does the scenario assume a home, office, public, or industrial environment? What kinds of equipment are most commonly used together in the scenario being addressed? What services will be provided, e.g., voice communications, entertainment, personal communications, data, or mission critical or life critical real-time data? Characteristics of the services such as reliability, range, delay, and interaction with other services or networks should also be described.

Each scenario will contain one or more usage models. A well-prepared usage model answers at least the following questions:

¹¹ In this document, the term “policy” is used generally to mean a radio policy for use in a policy-defined radio. Other uses of the term “policy,” such as “policy makers,” are clear by their context. See IEEE Std 1900.1-2008 [B15] for a specific definition of this use of policy.

- What frequency bands are involved?
- What kind of use environment is being considered, e.g., home, office, industrial, or hospital?
- What device population and population density is anticipated?
- How will these devices be used?
- What is the distribution of the systems' transmitters and receivers?

The answers to these questions will allow the analyst to identify the important variables necessary for the analysis.

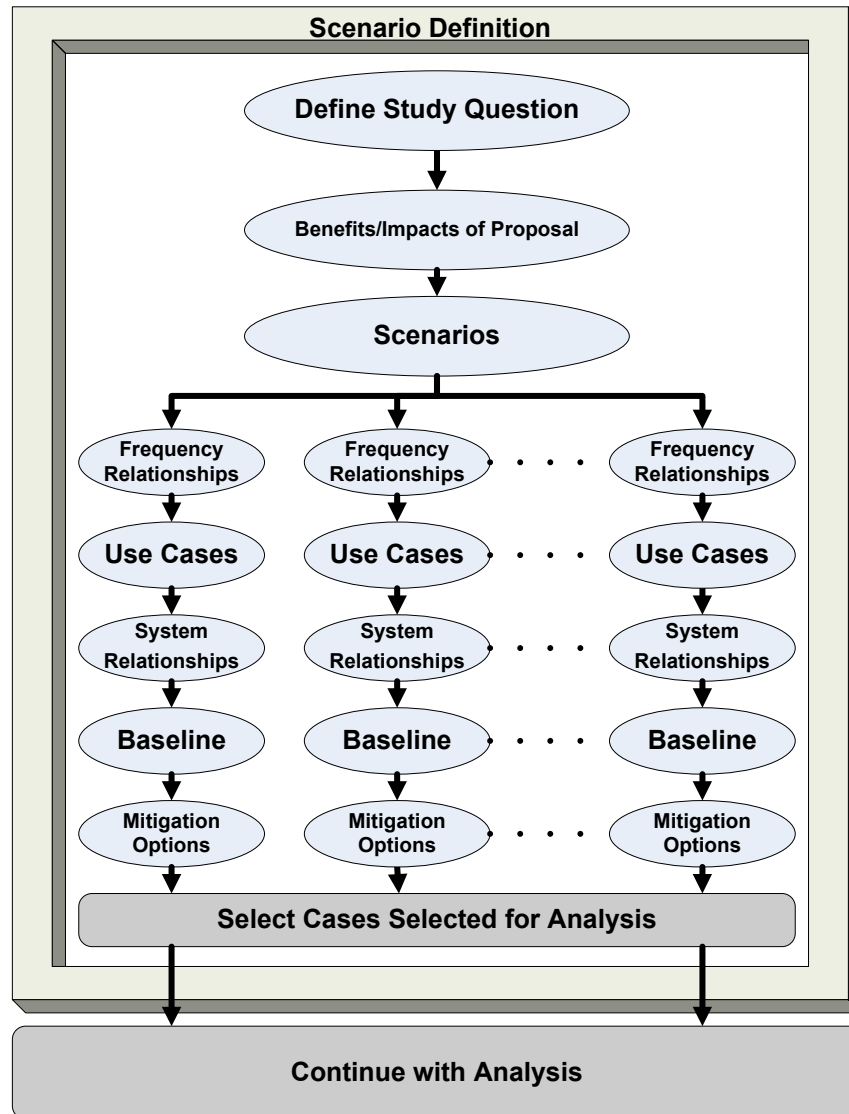


Figure 3 —Process diagram of the scenario definition clause

The scenario provides the understanding from which the technical variables of the analysis are derived. Once the analyst has defined the scenario, it is possible to identify the radio services involved, their characteristics, and the potential interactions. The scenario definition sets the stage for the following steps of the analysis:

- Defining the interference criteria
- Identifying variables and behaviors
- Performing the modeling and analysis

6.4.1 Frequency relationships

The following frequency regions, depicted in Figure 4, should be considered for each analysis:

- Co-channel
- Adjacent channel (directly adjacent channels)
- In-band, nonadjacent channels (noncontiguous, in-band channels)
- Band edge (near-band edge and out-of-band)
- Out-of-band (far out-of-band)

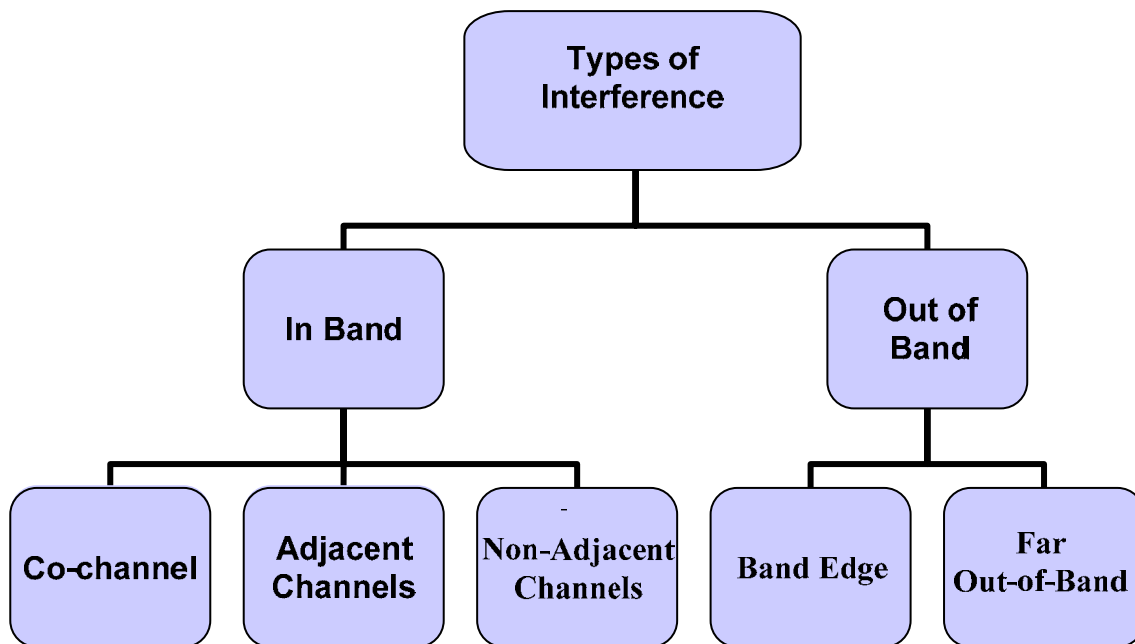


Figure 4 —Frequency relationships

The analysis should quantitatively specify the frequency boundaries defining each region. For each frequency region, a review is necessary of the types of systems operating in that region. In 6.4.4, the various types of equipment operating in each frequency region and their characteristics, which are relevant to the question being studied, should be identified.

6.4.2 Usage model

This subsection of the report defines what usage models are to be considered in the analysis. When beginning an analysis, a great many usage models can be envisioned. Typically, after some consideration, a few usage models are found to be sufficient to define the question being studied. These defining models

may be the most significant or difficult or they may define the boundary for the analysis. The configuration and operation of both the source and recipient systems should be explicitly defined.

If there are usage models that are worse than those selected for study, the analysis will describe why those are rejected. Some possible reasons for rejecting a use model or an entire scenario may be that it occurs too infrequently, it is beyond the purpose of a particular analysis for other reasons, or the consequences of interference are of less practical significance than the cases selected.

The material provided in this subsection of the report provides the foundation for the interference event determination in 7.4.

6.4.3 Characteristics of usage model

After explaining in 6.4.2 how users will use the system, the technical characteristics of that usage model should be identified. This sub-section of the report states how the use model interacts with the technology being considered.

Both the source and recipient system characteristics should be explicitly defined.

NOTE—A technology likely to be used in implementing DySPAN is software-defined radio (SDR) technology. SDRs are reconfigurable, which means many parameters documented in the analysis could be subject to change in the field, either inadvertently or by hackers. Describing the reconfiguration controls and security measures used to protect the devices and networks using them will be very important for a full treatment and understanding of a scenario, but SDR security is beyond the scope of this document.

6.4.3.1 Spatial and power characteristics

This subsection shall contain a description of the following characteristics:

- Spatial distribution of transmitters and receivers
- Mobility of devices
- Transmission power and power control
 - 1) Power limits
 - 2) Dynamic power control (as applicable)
- Directionality of antenna and control of directionality
- System range and coverage
- Operating margins expected or used in system planning

In cases where an adaptive user will coexist with a recipient device or system, the variables that allow for spatial reuse of spectrum are very important. For example, in a situation where the recipient device or system transmits on a relatively static basis, such as a broadcast service, the dynamic user is required to operate with the spatial and power limits required by the recipient device or system's transmission and reception characteristics and spatial distribution.

Both the source and recipient system spatial characteristics should be explicitly defined.

6.4.3.2 Temporal characteristics

This subsection of the report shall contain a description of the following characteristics:

- Transmitter and receiver temporal characteristics (continuous, packetized, time division, carrier sensed) and temporal distributions

- Acquisition and abandonment time of dynamic systems (if applicable)
- TDMA parameters (if applicable)
- Time division or frequency division duplexing (if applicable)
- Timescale of cooperation
- Time-dependent traffic parameters.

Source and recipient devices may have distinct traffic characteristics over time. The source may have peak traffic usage at a period of the day when the recipient is generally off or operating below capacity. When an adaptive user will be operating with a recipient device or system that transmits periodically rather than continuously, the opportunity may exist for frequency channels to be used during quiet periods between the recipient device's or the system's transmission. In such a situation, the temporal characteristics of the recipient device or the system's transmission, and the expectation of the receivers during non-transmission intervals, becomes significant. The time required to detect a recipient device's or a system's signal and to abandon the channel is a major concern. In addition, source system transmissions during intervals expected to be quiet by the recipient receiver may decrease the recipient battery life due to processing of the unexpected signals. The source transmissions also may block a recipient from receiving signals from other transmitters or block the recipient from replying to a signal due to unexpected channel occupancy.

Sources and recipients may cooperate to avoid interference over very different timescales. Longer timescales allow manual frequency and siting coordination. Shorter timescales may allow coordination through automated sense and avoid techniques. In some cases, it may be possible to interleave transmissions on an ongoing basis. When this occurs, multiple systems can operate in an ongoing fashion, separated by the temporal characteristics of their transmission.

Both the source and recipient system temporal characteristics should be explicitly defined.

6.4.3.3 Frequency characteristics

This subsection of the report shall contain a description of the following characteristics:

- Channel plans
- Regulatory frequency limits
- Spurious and out-of-band emissions
- Intended frequency range of operation
- Device frequency capability or possible frequency range of operation
- Other frequency characteristics

Both the source and recipient system frequency characteristics should be explicitly defined.

6.4.3.4 Other orthogonal variables

This subsection of the report shall contain a description of other relevant orthogonal variables that may affect coexistence:

- Polarization
- MIMO
- CDMA techniques
- Diversity