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IEEE Std 802.16.2-2001

IEEE Recommended Practice for Local and metropolitan area networks

Coexistence of Fixed Broadband Wireless Access Systems

IEEE Computer Society

Sponsored by the
LAN/MAN Standards Committee

and the
IEEE Microwave Theory and Techniques Society

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Abstract: This IEEE recommended practice provides guidelines for minimizing interference in fixed broadband wireless access (BWA) systems operating in the frequency range 10 to 66 GHz, with particular focus on the range 23.5 to 43.5 GHz. It analyzes coexistence scenarios and provides guidance for system design, deployment, coordination, and frequency usage.

Keywords: coexistence, fixed broadband wireless access (BWA), interference, local multipoint distribution service (LMDS), millimeter wave, multipoint, point-to-multipoint, radio, wireless metropolitan area network (WirelessMAN®) standard

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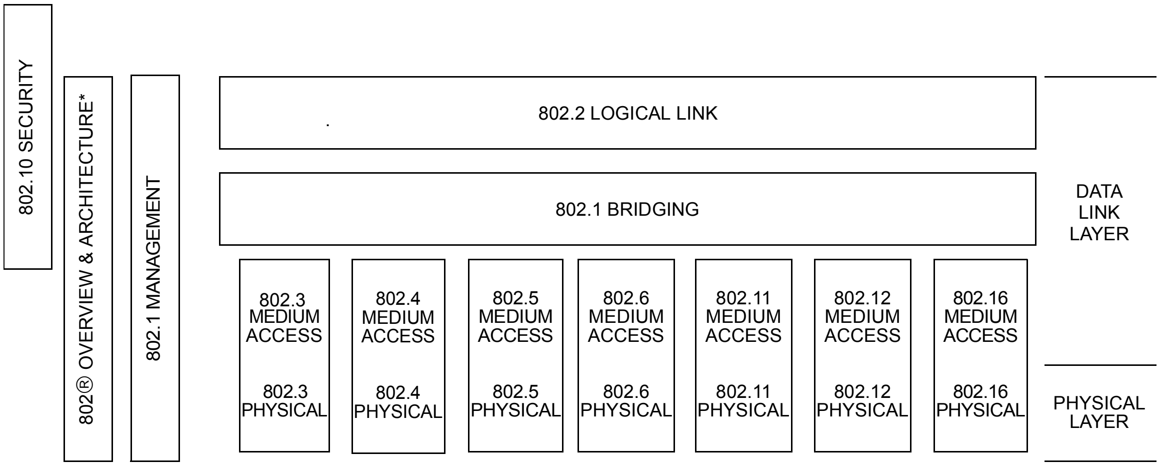
Introduction

(This introduction is not a part of IEEE Std 802.16.2-2001, IEEE Recommended Practice for Local and metropolitan area networks—Coexistence of Fixed Broadband Wireless Access (BWA) Systems.)

This Recommended Practice provides guidelines for minimizing interference in fixed broadband wireless access systems. Pertinent coexistence issues are addressed. Recommended engineering practices provide guidance for system design, deployment, coordination, and frequency usage. This document covers frequencies of 10 to 66 GHz frequencies in general, but it is focused on 23.5 to 43.5 GHz. If followed by manufacturers and operators, it should allow a wide range of equipment to coexist in a shared environment with acceptable mutual interference.

Other non-IEEE standards committees and regulatory bodies have done similar studies and developed guidelines or rules. In Annex D, work from some of these bodies has been summarized.

This Recommended Practice is intended as a companion to the IEEE 802.16 Standard Air Interface for Fixed Broadband Wireless Access Systems, which is part of a family of standards for local and metropolitan area networks. The relationship between the IEEE 802.16 standard and other members of the family is shown below. (The numbers in the figure refer to IEEE standard numbers.)



* Formerly IEEE Std 802.1A.

This family of standards deals with the Physical and Data Link Layers as defined by the International Organization for Standardization (ISO) Open Systems Interconnection Basic Reference Model (ISO/IEC 7498-1:1994). The access standards define several types of medium access technologies and associated physical media, each appropriate for particular applications or system objectives. Other types are under investigation.

The standards defining the technologies noted above are as follows:

• IEEE Std 802[1]:	*Overview and Architecture*. This standard provides an overview to the family of IEEE 802® Standards. This document forms part of the IEEE 802.1 scope of work.
• ANSI/IEEE Std 802.1B and 802.1K [ISO/IEC 15802-2]:	*LAN/MAN Management*. Defines an Open Systems Interconnection (OSI) management-compatible architecture, and services and protocol elements for use in a LAN/MAN environment for performing remote management.
• ANSI/IEEE Std 802.1D	*Medium Access Control* (*MAC) Bridges*. Specifies an architecture and protocol for the [ISO/IEC 15802-3]: interconnection of IEEE 802 LANs below the MAC service boundary.
• ANSI/IEEE Std 802.1E [ISO/IEC 15802-4]:	*System Load Protocol*. Specifies a set of services and protocol for those aspects of management concerned with the loading of systems on IEEE 802 LANs.
• ANSI/IEEE Std 802.1F	*Common Definitions and Procedures for IEEE 802 Management Information*.
• ANSI/IEEE Std 802.1G [ISO/IEC 15802-5]:	*Remote Media Access Control (MAC) Bridging*. Specifies extensions for the interconnection, using non-LAN systems communication technologies, of geographically separated IEEE 802 LANs below the level of the logical link control protocol.
• ANSI/IEEE Std 802.1H [ISO/IEC TR 11802-5]	*Recommended Practice for Media Access Control (MAC) Bridging of Ethernet V2.0 in IEEE 802 Local Area Networks*.
• ANSI/IEEE Std 802.1Q	*Virtual Bridged Local Area Networks*. Defines an architecture for Virtual Bridged LANs, the services provided in Virtual Bridged LANs, and the protocols and algorithms involved in the provision of those services.
• ANSI/IEEE Std 802.2 [ISO/IEC 8802-2]:	*Logical Link Control*.
• ANSI/IEEE Std 802.3 [ISO/IEC 8802-3]:	*CSMA/CD Access Method and Physical Layer Specifications*.
• ANSI/IEEE Std 802.4 [ISO/IEC 8802-4]:	*Token Bus Access Method and Physical Layer Specifications*.
• ANSI/IEEE Std 802.5 [ISO/IEC 8802-5]:	*Token Ring Access Method and Physical Layer Specifications*.
• ANSI/IEEE Std 802.6 [ISO/IEC 8802-6]:	*Distributed Queue Dual Bus Access Method and Physical Layer Specifications*.
• ANSI/IEEE Std 802.10:	*Interoperable LAN/MAN Security*. Currently approved: Secure Data Exchange (SDE).

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[1] The IEEE 802 Architecture and Overview Specification, originally known as IEEE Std 802.1A, has been renumbered as IEEE Std 802. This has been done to accommodate recognition of the base standard in a family of standards. References to IEEE Std 802.1A should be considered as references to IEEE Std 802.

• ANSI/IEEE Std 802.11:	*Wireless LAN Medium Access Control (MAC) Sublayer and* [ISO/IEC 8802-11]Physical Layer Specifications.
• ANSI/IEEE Std 802.12: [ISO/IEC 8802-12]	*Demand Priority Access Method, Physical Layer and Repeater Specification*.
• IEEE Std 802.15:	*Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for: Wireless Personal Area Networks.*
• IEEE Std 802.16:	*Standard Air Interface for Fixed Broadband Wireless Access Systems*.
• IEEE Std 802.17:	*Resilient Packet Ring Access Method and Physical Layer Specifications.*

In addition to the family of standards, the following is a recommended practice for a common physical layer technology:

• IEEE Std 802.7:	*IEEE Recommended Practice for Broadband Local Area Networks*.

The reader of this standard is urged to become familiar with the complete family of standards.

Conformance test methodology

An additional standards series, identified by the number 1802, has been established to identify the conformance test methodology documents for the IEEE 802 family of standards. Thus the conformance test documents for IEEE 802.3 are numbered IEEE 1802.3, the conformance test documents for IEEE 802.5 will be IEEE 1802.5, and so on. Similarly, ISO will use IEEE 18802 to number conformance test standards for IEEE 8802 standards.

Interpretations and errata

Interpretations and errata associated with this standard may be found at one of the following Internet locations:

— http://standards.ieee.org/reading/ieee/interp/

— http://standards.ieee.org/reading/ieee/updates/errata/

One such interpretation, on the topic of out-of-block unwanted emissions, exists at the time of publication.

Participants

This document was developed by the IEEE 802.16 Working Group on Broadband Wireless Access, which is responsible for Wireless Metropolitan Area Network (WirelessMAN™) Standards and Recommended Practices. Primary development was carried out by the Working Group's Task Group 2. When the draft of this standard passed Working Group Letter Ballot and Sponsor Ballot, Task Group 2 was Chaired by Philip Whitehead. J. Leland Langston was the original Task Group 2 Chair, from May 1999 until July 2000. Subsequently, Andy McGregor served in that capacity until November 2000.

Roger B. Marks served as Technical Editor of this standard, with contributions from Paul Beastall. Earlier editors were Muya Wachira, who edited the draft that passed Working Group Letter Ballot; Vito Scaringi, who edited the draft first presented for Working Group Letter Ballot; and Rebecca Chan. Comment resolutions were developed by a Comment Resolution Committee chaired by Philip Whitehead, and included Rémi Chayer, Jack Garrison, Barry Lewis, Paul Thompson, and Robert Whiting.

At the time the draft of this standard passed Working Group Letter Ballot, the IEEE 802.16 Working Group on Broadband Wireless Access had the following officers:

Roger B. Marks, *Chair*
Brian G. Kiernan, *Vice Chair*
Carl J. Bushue, *Secretary*

Louis Olsen served as Vice Chair during the initial development of this document, until September 2000. J. Scott Marin served as Working Group Secretary during the draft's development until December 2000.

The following members of the IEEE 802.16 Working Group on Broadband Wireless Access participated in the Working Group Letter Ballot in which the draft of this standard was approved:

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

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Contents

IEEE Recommended Practice for
Local and metropolitan area networks

Coexistence of Fixed Broadband Wireless Access Systems

1. Overview

This document provides recommended practice for the design and coordinated deployment of fixed Broadband Wireless Access (BWA) systems to control interference and promote coexistence. This Recommended Practice is divided into nine clauses. Subclause 1.1 provides the scope of the Recommended Practice. Clause 2 lists references to other standards that are useful in applying this Recommended Practice. Clause 3 provides definitions and abbreviations that are either not found in other standards or have been modified for use with this Recommended Practice. Clause 4 provides a summary of fixed BWA coexistence recommendations and guidelines. Clause 5 provides an overview of fixed BWA systems including system architecture and medium overview. Clause 6 deals with equipment design parameters, including radiated power, spectral masks and antenna patterns, and includes limits for both in-band and out-of-band fixed BWA system emissions. Also included in Clause 6 are recommended tolerance levels for certain receiver parameters, including noise floor degradation and blocking performance, for interference received from other fixed BWA systems as well as from other systems. Clause 7 provides the methodology to be used in the deployment and coordination of fixed BWA systems, including band plans, separation distances, and power spectral flux density limits to facilitate coordination and enable successful deployment of fixed BWA systems with tolerable interference. Clause 8 consists of interference and propagation evaluation examples of coexistence in a point-to-multipoint (PMP) environment, indicating some of the models, simulations and analyses used in the preparation of this Recommended Practice. Clause 9 describes some of the mitigation techniques that could be employed in case of co-channel interference between systems operating in adjacent areas or in case of undesired signals caused by natural phenomena and other unintentional sources.

1.1 Scope

The intent of this document is to define a set of consistent design and deployment recommendations that promote coexistence for fixed BWA systems. The recommendations have been developed and substantiated by analyses and simulations specific to the deployment and propagation environment appropriate to terrestrial fixed BWA intersystem interference experienced between operators licensed for fixed BWA. These recommendations, if followed by manufacturers and operators, will facilitate a wide range of equipment to coexist in a shared environment with acceptable mutual interference.

The scope of this Recommended Practice includes the examination of interference between systems deployed across geographic boundaries in the same frequency blocks and systems deployed in the same geographic area in adjacent frequency blocks. This document emphasizes coexistence practices for point-to-multipoint systems. This Recommended Practice does not cover coexistence issues due to intrasystem frequency reuse within the operator's authorized band, and it does not consider the impact of interference created by fixed BWA systems on non-BWA terrestrial and satellite systems.

This document is not intended to be a replacement for applicable regulations, which would take precedence.

2. Normative references

This Recommended Practice shall be used in conjunction with the following:

ETSI EN 301 390 V1.1.1. (2000-12), Fixed Radio Systems; Point-to-Point and Point-to-Multipoint Systems; Spurious Emissions and Receiver Immunity at Equipment/Antenna Port of Digital Fixed Radio Systems.[1]

IEEE P802.16/D3, Draft Standard for Local and Metropolitan Area Networks—Part 16: Standard Air Interface for Fixed Broadband Wireless Access Systems.[2]

Recommendation ITU-R F.1509: Technical and Operational Requirements that Facilitate Sharing between Point-to-Multipoint Systems in the Fixed Service and the Inter-Satellite service in the band 25.25–27.5 GHz.[3]

3. Definitions and abbreviations

For the purposes of this Recommended Practice, the following terms and definitions apply. The Authoritative Dictionary of IEEE Standards Terms [B9][4] should be referenced for terms not defined in this clause.

Other standards documents (e.g., [B19]) employ comparable definitions and abbreviations to those that follow. However, while comparable, they differ in a number of cases.

3.1 Definitions

3.1.1 authorized band: The range of frequencies over which an operator is permitted to operate radio transmitters and receivers.

3.1.2 automatic transmit power control (ATPC): A technique used in BWA systems to adaptively adjust the transmit power of a transmitter to maintain the received signal level within some desired range.

3.1.3 base station (BS): A generalized equipment set providing connectivity, management, and control of the subscriber station.

3.1.4 broadband: Having instantaneous bandwidths greater than around 1 MHz and supporting data rates greater than about 1.5 Mbit/s.

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[1] ETSI publications are available from The European Telecommunications Standards Institute, 650, route des Lucioles, 06921 Sophia Antipolis, France (http://www.etsi.org/).

[2] This IEEE draft had not been approved by the IEEE-SA Standards Board at the time this publication went to press. For information about obtaining a draft, contact the IEEE.

[3] ITU-T publications are available from the International Telecommunications Union, Place des Nations, CH-1211, Geneva 20, Switzerland/Suisse (http://www.itu.int/).

[4] The numbers in brackets correspond to those of the bibliography in Annex G.

3.1.5 broadband wireless access (BWA): Wireless access in which the connection(s) capabilities are broadband.

3.1.6 cross-polar discrimination (XPD): The XPD of an antenna for a given direction is the difference in dB between the peak co-polarized gain of the antenna and the cross-polarized gain of the antenna in the given direction.

3.1.7 digital modulation: Digital modulation is the process of varying one or more parameters of a carrier wave (e.g., frequency, phase, amplitude, or combinations thereof) as a function of two or more finite and discrete states of a signal.

3.1.8 downlink: The direction from a base station to the subscriber station.

3.1.9 DS-3: A North American Common Carrier Multiplex level having a line rate of 44.736 Mbit/s.

3.1.10 fixed wireless access: Wireless access application in which the location of the SS and the BS are fixed in location.

3.1.11 frequency block: A contiguous portion of spectrum within a sub-band or frequency band, typically assigned to a single operator.

NOTE—A collection of frequency blocks may form a sub-band and/or a frequency band.

3.1.12 frequency division duplex (FDD): A duplex scheme in which uplink and downlink transmissions use different frequencies but are typically simultaneous.

3.1.13 Frequency Range 1: For purposes of this document, Frequency Range 1 refers to 10–23.5 GHz.

3.1.14 Frequency Range 2: For purposes of this document, Frequency Range 2 refers to 23.5–43.5 GHz.

3.1.15 Frequency Range 3: For purposes of this document, Frequency Range 3 refers to 43.5–66 GHz.

3.1.16 frequency re-use: A technique for employing a set of frequencies in multiple, closely-spaced cells and/or sectors for the purpose of increasing network traffic capacity.

3.1.17 harmonized transmissions: The use, by multiple operators, of a compatible transmission plan so that the base stations from different operators can share an antenna site and minimize interference. For FDD systems, this implies that each operator’s base station transmits in the same frequency sub-block (typically on a different channel) and that their terminals transmit in the corresponding paired sub-block. For TDD systems, harmonization implies frame, slot, and uplink/downlink synchronization.

3.1.18 intercell link: Intercell links interconnect two or more BS units, typically using wireless, fiber, or copper facilities.

3.1.19 mesh: A wireless network topology, known also as multipoint-to-multipoint, in which a number of subscriber stations within a geographic area are interconnected and can act as repeater stations. This allows a variety of routes between the core network and any subscriber station. Mesh systems do not have base stations in the conventional point-to-multipoint sense.

3.1.20 multicarrier system: A system using two or more carriers to provide service from a single transmitter.

3.1.21 multipoint (MP): A generic term for point-to-multipoint and multipoint-to-multipoint and variations or hybrids of these. Multipoint is a wireless topology in which a system provides service to multiple, geographically distributed, subscriber stations. The sharing of resources may occur in the time domain, frequency domain, or both.

3.1.22 multipoint-to-multipoint (MP-MP): See **mesh**.

3.1.23 OC-3: One hierarchical level in the Synchronous Optical Network transmission standard. The line rate for this level is 155.52 Mbit/s.

3.1.24 occupied bandwidth (B_0): For a single carrier, B_0 is the width of a frequency band such that, below its lower and above its upper frequency limits, the mean powers radiated are each equal to 0.5% of the total mean power radiated by a given emission. This implies that 99% of the total mean emitted power is within this band, and hence this bandwidth is also known as the 99% bandwidth.

When a multicarrier transmission uses a common amplifier stage, the occupied bandwidth of this composite transmission is defined by the following relationship:

$$B_{\mathrm{OM}} = 1/2\ B_{\mathrm{OU}} + 1/2\ B_{\mathrm{OL}} + (F_{\mathrm{OU}} - F_{\mathrm{OL}})$$

where:

B_{OM} = Occupied bandwidth of the multicarrier system
B_{OU} = Single-carrier Occupied Bandwidth of the uppermost sub-carrier
B_{OL} = Single-carrier Occupied Bandwidth of the lowermost sub-carrier
F_{OU} = Center frequency of the uppermost sub-carrier
F_{OL} = Center frequency of the lowermost sub-carrier

NOTE 1—This multicarrier definition will give a bandwidth which is slightly wider than the multicarrier 99% power bandwidth. For example, for six identical, adjacent carriers, B_{O} will contain 99.5% of the first carrier, 99.5% of the last carrier and 100% of the four middle carriers and therefore 99.8333% of total mean power.

NOTE 2—This definition applies to most analog and simple digital emissions (QAM, QPSK, etc.), but its applicability to other more complex modulation structures (e.g., OFDM, CDMA) is still to be determined.

3.1.25 out-of-block emissions (OOB emissions): Emissions from the edge of the authorized bandwidth up to 200% of the occupied bandwidth from the edge of the authorized bandwidth. These emissions occur both above and below the authorized bandwidth.

3.1.26 point-to-multipoint (PMP): In wireless systems, a topology wherein a base station simultaneously services multiple, geographically separated subscriber stations and each subscriber station is permanently associated with only one base station.

3.1.27 point-to-point: A topology in which a radio link is maintained between two stations.

3.1.28 power flux density (pfd): The radiated power flux per unit area.

3.1.29 power spectral flux density (psfd): The radiated power flux per unit bandwidth per unit area.

3.1.30 radiation pattern envelope (RPE): The RPE is a graph that represents the maximum sidelobe levels of an antenna over the specified band.

3.1.31 repeater station (RS): A station other than the BS that includes radio communication equipment facing two or more separate directions. Traffic received from one direction may be partly or wholly retransmitted in another direction. Traffic may also terminate and originate at the repeater station.

3.1.32 service area: A geographic area in which an operator is authorized to transmit.

3.1.33 spectrum disaggregation: Segregation of spectrum to permit several operators access to subportions of a licensee's authorized band.

3.1.34 spurious emissions: Emissions greater than 200% of the occupied bandwidth from the edge of the authorized bandwidth.

While this definition is specific to this Recommended Practice, International Telecommunications Union (ITU) Radio Regulation S.145 defines spurious emission as follows:

"Emission on a frequency or frequencies which are outside the necessary bandwidth and the level of which may be reduced without affecting the corresponding transmission of information. Spurious emissions include harmonic emissions, parasitic emissions, intermodulation products and frequency conversion products, but exclude out-of-band emissions."

3.1.35 subscriber station (SS): A generalized equipment set providing connectivity between subscriber equipment and a base station.

3.1.36 synchronized transmissions: Harmonized time-division duplex (TDD) transmissions.

3.1.37 terminal equipment: Terminal equipment encompasses a wide variety of apparatus at customer premises, providing end user services and connecting to subscriber station equipment (SS) via one or more interfaces.

3.1.38 time-division duplex (TDD): A duplex scheme where uplink and downlink transmissions occur at different times but may share the same frequency.

3.1.39 uplink: The direction from a subscriber station to the base station.

3.1.40 unwanted emissions: Out-of-band emissions, spurious emissions, and harmonics.

3.1.41 virtual block edge: A reference frequency used as a block edge frequency for testing of unwanted emissions so as to avoid effects of radio frequency (RF) block filters.

3.1.42 wireless access: End-user radio connection(s) to core networks.

3.2 Abbreviations

AdjCh	adjacent channel
ATPC	automatic transmit power control
AZ	azimuth
BER	bit error ratio
BFWA	broadband fixed wireless access
B_o	occupied bandwidth
BRAN	broadband radio access networks (an ETSI Project)
BS	base station
BW	bandwidth
BWA	broadband wireless access
CDF	cumulative distribution function
CDMA	code division multiple access
CEPT	Conférence Européenne des Administrations des Postes et des Télécommunications (European Conference of Postal and Telecommunication Administrations)

C/I	carrier-to-interference ratio
C/N	carrier-to-noise ratio
C/(N+I)	carrier-to-noise and interference ratio
CoCh	co-channel
CS	central station (used in Annexes only); or channel separation (in 6.1.3 only)
CW	continuous wave
dBc	decibels relative to the carrier level
dBi	gain relative to a hypothetical isotropic antenna
DRS	data relay satellite
DS-3	44.736 Mbit/s line rate
D/U	desired carrier-to-undesired carrier ratio
EL	elevation
EIRP	effective isotropic radiated power
EN	European norm
ERC	European Radiocommunications Committee
ETSI	European Telecommunications Standards Institute
FCC	Federal Communications Commission (USA)
FDD	frequency division duplex
FDMA	frequency division multiple access
FSPL	free space path loss
FWA	fixed wireless access
GSO	geostationary orbit
IA	interference area
IC	Industry Canada
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers, Inc.
I/N	interference-to-thermal noise ratio
ISOP	interference scenario occurrence probability
ITU	International Telecommunication Union
ITU-R	International Telecommunication Union – Radiocommunication Sector
LMCS	local multipoint communication system
LMDS	local multipoint distribution service
LOS	line of sight
MAN	metropolitan area network
MCL	minimum coupling loss
MP	multipoint
MP-MP	multipoint-to-multipoint
MWS	multimedia wireless systems
NFD	net filter discrimination
OC-3	155.52 Mbit/s line rate
OFDM	orthogonal frequency division multiplexing
OOB	out-of-block
PCS	personal communication service
pfd	power flux density
PMP	point-to-multipoint
psd	power spectral density
psfd	power spectral flux density
PTP	point-to-point
QAM	quadrature amplitude modulation
QPSK	quadrature phase shift keying
RA	Radiocommunications Agency
RABC	Radio Advisory Board of Canada
RF	radio frequency

RPE	radiation pattern envelope
RS	repeater station
RSS	Radio Standards Specifications
Rx	receive
SRSP	Standard Radio Systems Plan
SS	subscriber station
TDD	time division duplex
TDMA	time division multiple access
TS	terminal station
Tx	transmit
XPD	cross-polar discrimination

4. Summary of fixed BWA coexistence recommendations and guidelines

4.1 Document philosophy

Radio waves permeate through legislated (and even national) boundaries and emissions spill outside spectrum allocations. Coexistence issues between multiple operators are therefore inevitable.

The resolution of coexistence issues is an important factor for the fixed BWA industry. The Recommendations in 4.2 are provided for consideration by operators, manufacturers, and administrations to promote coexistence. Practical implementation within the scope of the current recommendations will assume that some portion of the frequency spectrum (at the edge of the authorized bandwidth) may be unusable. Furthermore, some locations within the service area may not be usable for deployment. Coexistence will rely heavily on the good-faith collaboration between spectrum holders to find and implement economical solutions.

The document analyzes coexistence using two scenarios:

— A co-channel (CoCh) scenario in which two operators are in either adjacent territories or territories within radio line of sight of each other and have the same spectrum allocation, and

— An adjacent Channel (AdjCh) scenario in which the licensed territories of two operators overlap and they are assigned adjacent spectrum allocations.

Coexistence issues may arise simultaneously from both scenarios as well as from these scenarios involving multiple operators.

As a starting point for the consideration of tolerable levels of interference into fixed BWA systems, ITU-R Recommendation F.758-2 [B16] details two generally accepted values for the interference-to-thermal noise ratio (*I/N*) for long-term interference into fixed service receivers. When considering interference from other services, it identifies an *I/N* value of –6 dB or –10 dB matched to specific requirements of individual systems. This approach provides a method for defining a tolerable limit that is independent of most characteristics of the victim receiver, apart from noise figure, and has been adopted for this Recommended Practice. The acceptability of any *I/N* value needs to be evaluated against the statistical nature of the interference environment. In arriving at the Recommendations in this document this evaluation has been carried out for an *I/N* value of –6 dB.

Clause 9 provides interference mitigation measures that can be utilized to solve coexistence problems. Because of the wide variation in subscriber station and base station distribution, radio emitter/receiver parameters, localized rain patterns, and the statistics of overlapping emissions in frequency and time, it is impossible to prescribe in this document which of the mitigation measures are appropriate to resolving a particular coexistence problem. In the application of these mitigation measures, identification of individual terminals or groups of terminals for modification is preferable to the imposition of pervasive restrictions.

Implementing the measures suggested in Recommendations 8–10 in 4.2 using the suggested equipment parameters in Clause 6 will, besides improving the coexistence conditions, have a generally positive effect on intrasystem performance. Similarly, simulations performed in the preparation of this Recommended Practice suggest that most of the measures undertaken by an operator to promote intrasystem performance will also promote coexistence.

It is outside the scope of this document to make recommendations that touch on intrasystem matters such as frequency plans, frequency reuse patterns, etc.

4.2 Recommendations

4.2.1 Recommendation 1

Adopt a criterion of 6 dB below receiver thermal noise (i.e., $I/N \leq -6$ dB) in the victim receiver as an acceptable level of interference from a transmission of an operator in a neighboring area. The document recommends this value in recognition of the fact that it is not practical to insist upon an "interference-free" environment. Having once adopted this value, the following are some important consequences:

— Each operator accepts a 1 dB degradation [the difference in dB between C/N and $C/(N + I)$] in receiver sensitivity. In some regard, an I/N of –6 dB becomes the fundamental criterion for coexistence. The very nature of the MP system is that receivers must accept interference from intrasystem transmitters. Although a good practice would be to reduce the intrasystem interference level to be well below the thermal noise level (see Recommendation 6 in 4.2.6), this is not always feasible. The actual level of external interference could be higher than the limit stated above and still be not controlling, or comparable to the operator's intrasystem interference. Thus, there is some degree of interference allocation that could be used to alleviate the coexistence problem.

— Depending upon the particular deployment environment, an operator's receiver may have interference contributions from multiple CoCh and AdjCh operators. Each operator should include design margin capable of simultaneously accepting the compound effect of interference from all other relevant operators. The design margin should be included preemptively at initial deployment, even if the operator in question is the first to deploy in a region and is not experiencing interference. All parties should recognize that, in predicting signal levels that result in the –6 dB interference value, it is difficult to be precise in including the aggregating effect of multiple terminals, the effect of uncorrelated rain, etc. Therefore, all parties should be prepared to investigate claims of interference even if the particular assessment method used to substantiate the –6 dB value predicts that there should not be any interference.

4.2.2 Recommendation 2

Each operator should take the initiative to collaborate with other known operators prior to initial deployment and prior to every relevant system modification. This recommendation should be followed even if an operator is the first to deploy in a region. To encourage this behavior for co-channel interference, this document introduces the concept of using power spectral flux density values to "trigger" different levels of initiatives taken by an operator to give notification to other operators. The specific trigger values and their application to the two deployment scenarios are discussed in Recommendation 5 (4.2.5) and Recommendation 6 (4.2.6) and in Clause 7

4.2.3 Recommendation 3

In the resolution of coexistence issues, in principle, incumbents and first movers should coordinate with operators who deploy at a later time. In resolving coexistence issues, it is legitimate to weigh the capital investment an incumbent operator has made in his or her system. It is also legitimate to weigh the capital investment required by an incumbent operator for a change due to coexistence versus the capital investment costs that the new operator will incur.

The logic behind this Recommendation is that some coexistence problems cannot be resolved simply by modifying the system of a new entrant into a region. Rather, they require the willingness of an incumbent to make modifications as well. It is recognized that this Recommendation is especially challenging in the AdjCh scenario where overlapping territories imply that the incumbent and the late-comer may be competing for the same clients. The reality of some spectrum allocations are such that AdjCh operators will be allocated side-by-side frequency channels. As is seen below, this is an especially difficult coexistence problem to resolve without co-location of the operator's cell sites.

4.2.4 Recommendation 4

No coordination is needed in a given direction if the transmitter is greater than 60 km from either the service area boundary or the neighbor's boundary (if known) in that direction. Based on typical fixed BWA equipment parameters and an allowance for potential LOS interference couplings, subsequent analysis indicates that a 60 km boundary distance is sufficient to preclude the need for coordination. At lesser distances, coordination may be required, but this is subject to a detailed examination of the specific transmission path details that may provide for interference link excess loss or blockage. This coordination criteria is viewed to be necessary and appropriate for both systems that conform to this Recommended Practice and those that do not.

4.2.5 Recommendation 5

(*This Recommendation applies to co-channel cases only.*)

Recommendation 2 above introduced the concept of using power spectral flux density "triggers" as a stimulus for an operator to take certain initiatives to collaborate with his or her neighbor. It is recommended that regulators specify the applicable trigger values for each frequency band, failing which the following values may be adopted:

The coordination trigger values (see Annex B) of –114 (dBW/m^2)/MHz (24, 26, and 28 GHz bands) and –111 (dBW/m^2)/MHz (38 and 42 GHz bands) are employed in the initiative procedure described in Recommendation 6 (4.2.6). The evaluation point for the trigger exceedance may be at either the victim operator's licensed area boundary, the interfering operator's boundary, or at a defined point in between depending to some extent on the specific geographic circumstances of the BWA licensing. These values were derived as that power spectral flux density values which, if present at a typical point-to-multipoint base station antenna and typical receiver, would result in approximately the –6 dB interference value cited in Recommendation 1. It should be emphasized that the trigger values are useful only as thresholds for taking certain actions with other operators; they do not make an absolute statement as to whether there is, or is not, interference potential. In cases of significant deployment of point-to-point systems alongside point-to-multipoint systems where protection of the point-to-point systems is mandated, tighter psfd trigger levels may be appropriate For example, –125 (dBW/m^2)/MHz at 38 GHz band is applied by some administrations to protect point-to-point links.

4.2.6 Recommendation 6

(*This Recommendation applies to co-channel cases only.*)

The "triggers" of Recommendation 5 and Recommendation 6 should be applied prior to deployment and prior to each relevant system modification. Should the trigger values be exceeded, the operator should try to modify the deployment to meet the trigger or, failing this, the operator should coordinate with the affected operator. Three existing coordination procedures are described in D, E, and F.

4.2.7 Recommendation 7

For same area/adjacent channel interference cases, analysis and simulation indicate that deployment may require an equivalent guard frequency between systems operating in close proximity and in adjacent frequency blocks. It is convenient to think of the “guard frequency” in terms of “equivalent channels” related to the systems operating at the edges of the neighboring frequency blocks. The amount of “guard frequency” depends on a variety of factors such as “out of block” emission levels and in some cases is linked to the probability of interference in given deployment scenarios. Clause 8 provides insight into some methods that can be employed to assess these situations, while Clause 9 describes some possible interference mitigation techniques. These mitigation techniques include frequency guard bands, recognition of cross-polarization differences, antenna angular discrimination, spatial location differences, and frequency assignment substitution.

In most co-polarized cases, where the transmissions in each block are employing the same channel bandwidth, the guard frequency should be equal to one equivalent channel. Where the transmissions in neighboring blocks employ significantly different channel bandwidths, it is likely that a guard frequency equal to one equivalent channel of the widest bandwidth system will be adequate. However, analysis suggests that, under certain deployment circumstances, this may not offer sufficient protection and that a guard frequency equal to one channel at the edge of each operator’s block may be required. Where administrations do not set aside guard channels, the affected operators would need to reach agreement on how the guard channel is apportioned between them. It is possible that, with careful and intelligent frequency planning, coordination, and/or use of orthogonal polarization or other mitigation techniques, all or partial use of this guard channel may be achieved. However, in order to minimize interference conflicts and at the same time maximize spectrum utilization, cooperative deployment between operators will be essential. This recommendation strongly proposes this.

4.2.8 Recommendation 8

Utilize antennas for the base station and subscriber stations at least as good as the Class 1 antennas described in 6.2. The coexistence simulations which led to the Recommendations contained herein revealed that a majority of coexistence problems are the result of main-beam interference. The sidelobe levels of the base station antennas are of a significant but secondary influence. The sidelobe levels of the subscriber antenna are of tertiary importance. In the context of coexistence, therefore, antennas such as those presented in 6.2 are sufficient. It should be emphasized that utilizing antennas with sidelobe (and polarization) performance better than the minimum will not degrade the coexistence performance and, in fact, is an effective mitigation technique for specific instances. In many cases, intrasystem considerations may place higher demands on antenna performance than those required for intersystem coordination.

4.2.9 Recommendation 9

Utilize an emission mask at least as good as that described in 6.1.3. The utility of emission masks for controlling adjacent channel coexistence issues is strongly dependent upon the separation of the two emitters in space and in frequency. In case of large spatial separation between emitters, the opportunity exists for an interfering emitter to be much closer to a receiver than the desired emitter. This unfavorable range differential can overwhelm even the best emission mask. Likewise, emission masks are most effective when at least one guard channel exists between allocations. The emission mask presented in 6.1.3 is most appropriate for the case in which a guard channel separates allocations and emitters are modestly separated. For cases with no guard band, it is recommended that co-location of harmonized base station emitters be considered before trying to improve emission masks.

4.2.10 Recommendation 10

Limit maximum EIRP in accordance with recommendations in 6.1.1 and use SS power control in accordance with recommendations in 6.1.1.5. The interests of coexistence are served by reducing the amount of EIRP emitted by base, SS, and repeater stations. The proposed maximum EIRP spectral density values are significantly less than allowed by some regulatory agencies but should be an appropriate balance between constructing robust fixed BWA systems and promoting coexistence.

4.2.11 Recommendation 11

In conducting analyses to predict power spectral flux density and for coordination purposes, the following should be considered:

a) Calculations of path loss to a point on the border should consider:
    1) Clear air (no rain) plus relevant atmospheric absorption
    2) Intervening terrain blockage
b) For the purpose of calculating psfd trigger compliance level, the psfd level at the service area boundary should be the maximum value which occurs at some elevation point up to 500 m above local terrain elevation. Equations (B.2) and (B.3) in Annex B should be used to calculate the psfd limits.
c) Actual electrical parameters (e.g., EIRP, antenna patterns, etc.) should be used.
d) Clear sky propagation (maximum path length) conditions should be assumed. Where possible, use established ITU-R Recommendations relating to propagation (e.g., Recommendation ITU-R P.452 [B20]).

4.3 Suggested guidelines for geographical and frequency spacing

This subclause and Clause 8 indicate some of the models, simulations, and analysis used in the preparation of this Recommended Practice. While a variety of tools may be used, the scenarios studied below should be considered when coordination is required.

Guidelines for geographical and frequency spacing of fixed BWA systems that would otherwise mutually interfere are given in 8.1 for each of a number of interfering mechanisms. This subclause summarizes the overall guidelines, taking into account all the identified interference mechanisms.

The two main deployment scenarios are as follows:

- Co-channel systems that are geographically spaced
- Systems that overlap in coverage and (in general) require different frequencies of operation

The most severe of the several mechanisms that apply to each case determines the guideline spacing, as shown in Table 1:

The guidelines are not meant to replace the coordination process described in Clause 7. However, in many (probably most) cases, these guidelines will provide satisfactory psfd levels at system boundaries. The information is therefore valuable as a first step in planning the deployment of systems.

5. System overview

BWA generally refers to fixed radio systems used primarily to convey broadband services between users' premises and core networks. The term "broadband" is usually taken to mean the capability to deliver significant bandwidth to each user. In ITU terminology, and in this document, broadband transmission refers to transmission rate of greater than around 1.5 Mbit/s, though many BWA networks support significantly

Table 1—Summary of the guidelines for geographical and frequency spacing

Dominant interference path (note 1)	Scenario	Spacing at which interference is below target level (generally 6 dB below receiver noise floor)
PMP BS to PMP BS	Adjacent area, same channel	60 km (note 5)
Mesh SSs to PMP BS	Adjacent area, same channel	12 km (note 2)
PMP BS to PMP BS	Same area, adjacent channel	1 guard channel (notes 3 and 5)
Mesh SSs to PMP SS	Same area, adjacent channel	1 guard channel (note 4)

NOTES
1—The dominant interference path is that which requires the highest guideline geographical or frequency spacing.
2—The 12 km value is based on a BS at a typical 50 m height. For other values, the results change to some extent, but are always well below the 60 km value calculated for the PMP – PMP case.
3—The single guard channel spacing is based on both interfering and victim systems using the same channel size. Where the transmissions in neighboring blocks employ significantly different channel bandwidths then it is likely that a guard frequency equal to one equivalent channel of the widest bandwidth system will be adequate. However analysis suggests that, under certain deployment circumstances, this may not offer sufficient protection and that a guard frequency equal to one channel at the edge of each operator's block may be required.
4—The single guard channel spacing for mesh to PMP is based on both interfering and victim systems using the same channel size. This may be reduced in some circumstances. Where the transmissions in neighboring blocks employ significantly different channel bandwidths, it is likely that a guard frequency equal to one equivalent channel of the widest bandwidth system will be adequate. However, analysis suggests that under certain deployment circumstances this may not offer sufficient protection and that a guard frequency equal to one channel at the edge of each operator's block may be required.
5—In a case of harmonized FDD band plans and/or frequency reassignable TDD systems, the BS-to-BS case ceases to be dominant.

higher data rates. The networks operate transparently, so users are not aware that services are delivered by radio.A typical fixed BWA network supports connection to many user premises within a radio coverage area. It provides a pool of bandwidth, shared automatically among the users. Demand from different users is often statistically of low correlation, allowing the network to deliver significant bandwidth-on-demand to many users with a high level of spectrum efficiency. Significant frequency reuse is employed.

The range of applications is very wide and evolving quickly. It includes voice, data, and entertainment services of many kinds. Each subscriber may require a different mix of services; this mix is likely to change rapidly as connections are established and terminated. Traffic flow may be unidirectional, asymmetrical, or symmetrical, again changing with time. In some territories, systems delivering these services are referred to as multimedia wireless systems (MWS) in order to reflect the convergence between traditional telecommunications services and entertainment services.

These radio systems compete with other wired and wireless delivery means for the "first mile" connection to services. Use of radio or wireless techniques result in a number of benefits, including rapid deployment and relatively low "up-front" costs.

5.1 System architecture

Fixed BWA systems often employ multipoint architectures. The term multipoint includes point-to-multipoint (PMP) and multipoint-to-multipoint (MP-MP). The IEEE 802.16 Working Group on Broadband Wireless Access (see Clause 2) is developing standards for PMP systems with base stations and subscriber stations communicating over a fully specified air interface. A similar PMP standard is being developed within the "HIPERACCESS" topic within ETSI Project BRAN 7. Coexistence specifications for MWS (which includes the requirements for HIPERACCESS) are being prepared by the ETSI TM4 committee 3. In addition, a number of proprietary fixed BWA systems exist for which the air interface is not standardized.

5.1.1 PMP systems

PMP systems comprise base stations, subscriber stations and, in some cases, repeaters. Base stations use relatively wide-beam antennas, divided into one or several sectors providing up to 360-degrees coverage with one or more antennas. To achieve complete coverage of an area, more than one base station may be required. The connection between BSs is not part of the fixed BWA network itself, being achieved by use of radio links, fiber optic cable, or equivalent means.

Links between BSs may sometimes use part of the same frequency allocation as the fixed BWA itself. Routing to the appropriate BS is a function of the core network. Subscriber stations use directional antennas, facing a BS and sharing use of the radio channel. This may be achieved by various access methods, including frequency division, time division, or code division.

5.1.2 MP systems (Mesh)

Multipoint-to-multipoint (MP-MP) systems have the same functionality as PMP systems. Base stations provide connections to core networks on one side and radio connection to other stations on the other. A subscriber station may be a radio terminal or (more typically) a repeater with local traffic access. Traffic may pass via one or more repeaters to reach a subscriber. Antennas are generally narrow-beam directional types, with means for remote alignment.

5.2 System components

Fixed broadband wireless access systems typically include base stations (BS), subscriber stations (SS), subscriber terminal equipment, core network equipment, intercell links, repeaters, and possibly other equipment. A reference fixed BWA system diagram is provided in Figure 1. This diagram indicates the relationship between various components of a BWA system. BWA systems may be much simpler and contain only some elements of the network shown in Figure 1.[5] A fixed BWA system contains at least one BS and a number of SS units. In the figure, the wireless links are shown as zigzag lines connecting system elements.

Intercell links may use wireless, fiber, or copper facilities to interconnect two or more BS units. Intercell links may, in some cases, use in-band point to point (PTP) radios that provide a wireless backhaul capability between base stations at rates ranging from DS-3 to OC-3. Such PTP links may operate under the auspices of the PMP license.

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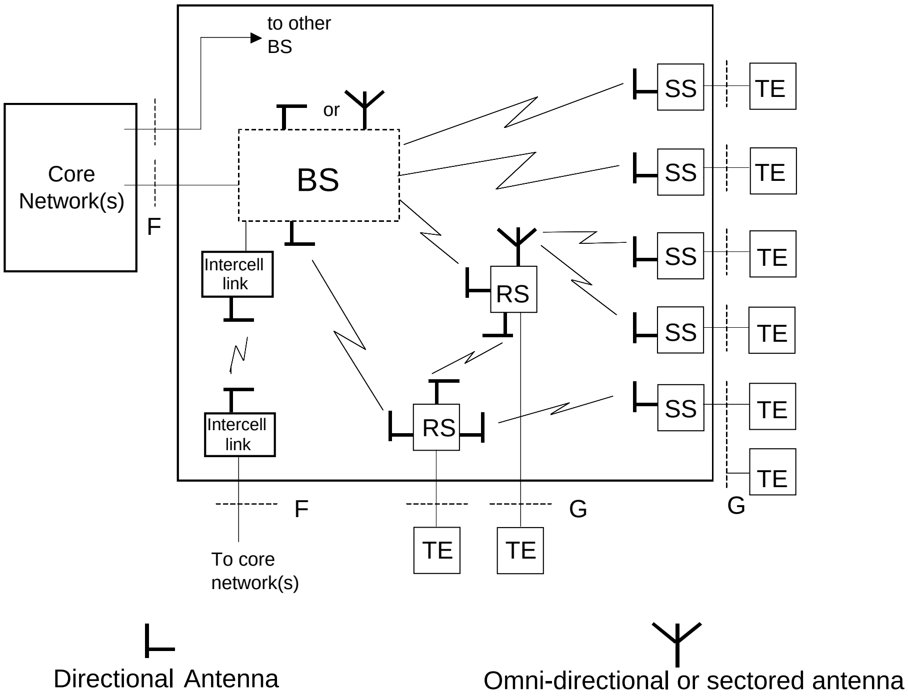


SOURCE: ETSI EN 301 390 V1.1.1. (2000-12), Fixed Radio Systems; Point-to-Point and Point-to-Multipoint Systems; Spurious Emissions and Receiver Immunity at Equipment/Antenna Port of Digital Fixed Radio Systems.

Figure 1—Interference sources to a fixed BWA BS

Antennas with a variety of radiation patterns may be employed. In general, a subscriber station utilizes a highly directional antenna. Some systems deploy repeaters. In a PMP system, repeaters are generally used to improve coverage to locations where the BS(s) have no line of sight within their normal coverage area(s), or alternatively to extend coverage of a particular BS beyond its normal transmission range. A repeater relays information from a BS to one or a group of SSs. It may also provide a connection for a local subscriber station. A repeater may operate on the same downlink frequencies as those frequencies that it uses, facing the BS, or it may use different frequencies (i.e., demodulate and remodulate the traffic on different channels). In MP-MP systems, most stations are repeaters that also provide connections for local subscribers.

The boundary of the fixed BWA network is at the interface points F and G of Figure 1. The F interfaces are points of connection to core networks and are generally standardized. The G interfaces, between subscriber stations and terminal equipment, may be either standardized or proprietary.

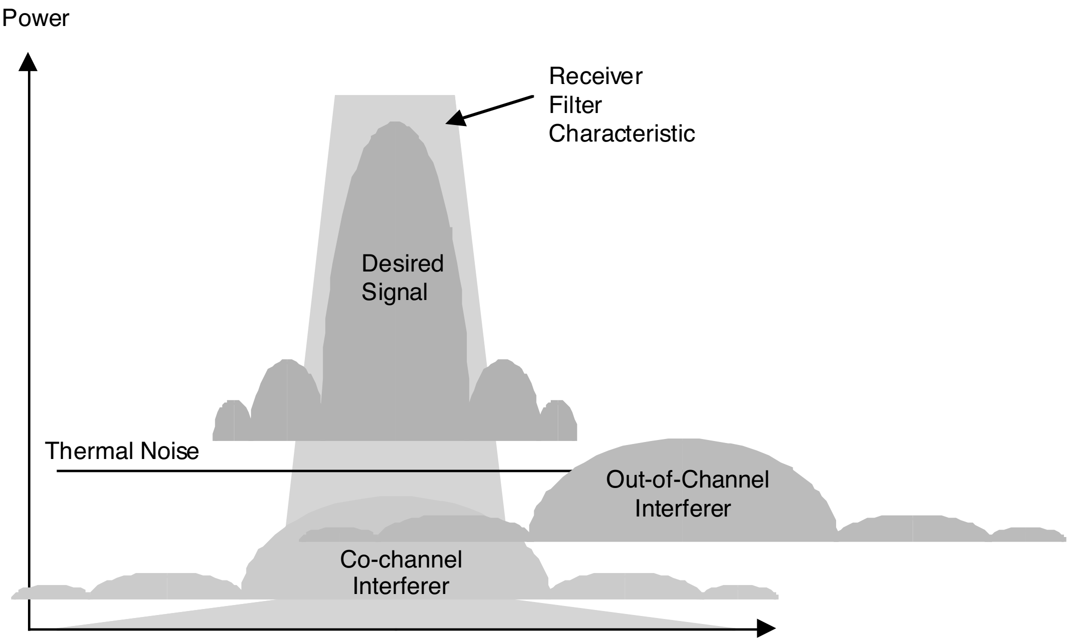
5.3 Medium overview

Electromagnetic propagation over Frequency Ranges 1–3 (10–66 GHz) is relatively nondispersive, with occasional but increasingly severe rain attenuation as frequency increases. Absorption of emissions by terrain and human-generated structures is severe, leading to the normal requirement for optical line-of-sight between transmit and receive antennas for satisfactory performance. Radio systems in this frequency regime are typically thermal or interference noise-limited (as opposed to multipath-limited) and have operational ranges of a few kilometers due to the large free-space loss and the sizable link margin which has to be reserved for rain loss. At the same time, the desire to deliver sizable amounts of capacity promotes the use of higher-order modulation schemes with the attendant need for large *C/I* for satisfactory operation. Consequently, the radio systems are vulnerable to interference from emissions well beyond their operational range. This is compounded by the fact that the rain cells producing the most severe rain losses are not uniformly distributed over the operational area This creates the potential for scenarios in which the desired signal is severely attenuated but the interfering signal is not.

5.3.1 Interference scenarios

5.3.1.1 Forms of interference

Interference can be classified into two broad categories: co-channel interference and out-of-channel interference. These manifest themselves as shown in Figure 2.[6]



SOURCE: ETSI EN 301 390 V1.1.1. (2000-12), Fixed Radio Systems; Point-to-Point and Point-to-Multipoint Systems; Spurious Emissions and Receiver Immunity at Equipment/Antenna Port of Digital Fixed Radio Systems.

Figure 2—Forms of interference

Figure 2 illustrates the power spectrum of the desired signal and co-channel interference in a simplified example. Note that the channel bandwidth of the co-channel interferer may be wider or narrower than the desired signal. In the case of a wider co-channel interferer (as shown), only a portion of its power will fall within the receive filter bandwidth. In this case, the interference can be estimated by calculating the power arriving at the receive antenna and then multiplying by a factor equal to the ratio of the filter's bandwidth to the interferer's bandwidth.

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An out-of-channel interferer is also shown. Here, two sets of parameters determine the total level of interference as follows:

— A portion of the interferer's spectral sidelobes or transmitter output noise floor falls co-channel to the desired signal; i.e., within the receiver filter's passband. This can be treated as co-channel interference. It cannot be removed at the receiver; its level is determined at the interfering transmitter. By characterizing the power spectral density of sidelobes and output noise floor with respect to the main lobe of a signal, this form of interference can be approximately computed in a manner similar to the co-channel interference calculation, with an additional attenuation factor due to the suppression of this spectral energy with respect to the main lobe of the interfering signal.The main lobe of the interferer is not completely suppressed by the receiver filter of the victim receiver. No filter is ideal, and residual power, passing through the stopband of the filter, can be treated as additive to the co-channel interference present. The level of this form of interference is determined by the performance of the victim receiver in rejecting out-of-channel signals, sometimes referred to as "blocking" performance. This form of interference can be simply estimated in a manner similar to the co-channel interference calculation, with an additional attenuation factor due to the relative rejection of the filter's stopband at the frequency of the interfering signal.

Quantitative input on equipment parameters is required to determine which of the two forms of interference from an out-of-channel interferer will dominate.

5.3.1.2 Acceptable level of interference

A fundamental property of any millimeter-wave fixed BWA system is its link budget, in which the range of the system is computed for a given availability, with given rain fading. During the designed worst-case rain fade, the level of the desired received signal will fall until it just equals the receiver thermal noise, kTBF, (where *k* is Boltzmann's constant, *T* is the temperature, *B* is the receiver bandwidth, and *F* is the receiver noise), plus the specified signal-to-noise ratio of the receiver. A way to account for interference is to determine $C/(N + I)$, the ratio of carrier level to the sum of noise and interference. For example, consider a receiver with 6 dB noise figure. The receiver thermal noise is –138 dBW/MHz. Interference of –138 dBW/MHz would double the total noise, or degrade the link budget by 3 dB. Interference of –144 dBW/MHz, 6 dB below the receiver thermal noise, would increase the total noise by 1 dB to –137 dBW/MHz, degrading the link budget by 1 dB.

For a given receiver noise figure and antenna gain in a given direction, the link budget degradation can be related to a received power flux density tolerance. In turn, this tolerance can be turned into separation distances for various scenarios.

5.3.1.3 Interference paths

5.3.1.3.1 Victim BS

Figure 3 shows main sources of interference where the victim receiver is a fixed BWA base station, with a sectoral-coverage antenna.

The victim BS is shown as a black triangle on the left, with its radiation pattern represented as ellipses. The desired SS transmitter is shown on lower right of figure. In the worst case, the desired signal travels through a localized rain cell, and is received at minimum signal strength. Thus, interference levels close to the thermal noise floor are significant.

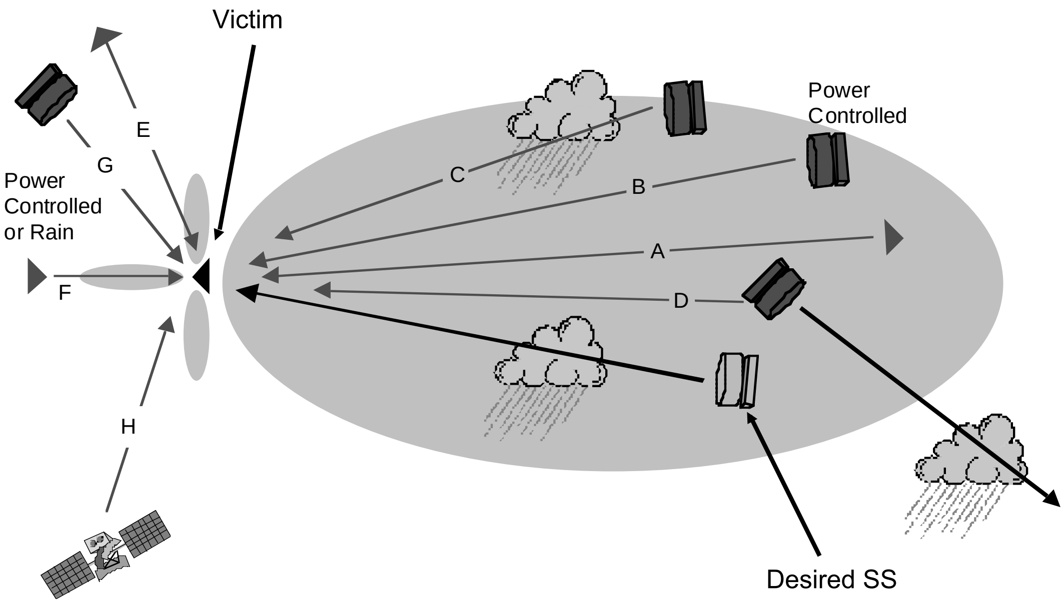


Figure 3—Interference sources to a fixed BWA BS

The letters in Figure 3 illustrate several cases of interference to a base station.

Case A shows BS-to-BS interference in which each BS antenna is in the main beam of the other. This case could occur commonly, as sector coverage angles tend to be wide—up to 90º. In fact, a victim BS could tend to see the aggregate power of several BSs. In addition, BS antennas tend to be elevated, with a high probability of a line-of-sight path to each other. As rain cells can be very localized, it is quite conceivable that the interferer travels on a path relatively unattenuated by rain, while the desired signal is heavily attenuated. BS-to-BS interference can be reduced by ensuring that there is no co-channel BS transmission on frequencies being used for reception at other BSs. This is possible with FDD through cooperative band planning, whereby vendors agree to use a common sub-band for BS transmissions and another common subband for BS reception.

Case B shows SS-to-BS interference in which each antenna is in the main beam of the other. As SS antenna gain is much higher than the BS antenna gain, this might appear to be the worst possible case. However, fixed BWA PMP systems can safely be assumed to employ uplink adaptive power control at subscriber stations. (Power control is required to equalize the received signal strength arriving at a BS from near and far SSs on adjacent channels. Note that active control of downlink power from BS transmitters is usually not employed, as the BS signal is received by a variety of SSs, both near and far, and power control would tend to create an imbalance in the level of signals seen from adjacent sectors.) Assuming that the subscriber station in Case B sees clear air, it can be assumed to have turned its power down, roughly in proportion to the degree of fade margin of its link. Note, however, that power control is imperfect, so the degree of turndown may be less than the fade margin. The turn-down compensates for the fact that the SS antenna has such high gain, so the net effect is that Case B may not be more severe than Case A. In addition, the narrow beamwidth of a SS antenna ensures that Case B is much less common an occurrence than Case A. However, Case B interference cannot be eliminated by band planning. Case B also covers interference generated by terrestrial point-to-point transmitters.

Case C is similar to Case B, except the interferer is assumed to see a rain cell and therefore does not turn down its power. However, as the interferer's beamwidth is narrow, the interference must also travel through this rain cell on the way to the victim receiver; hence, the net result is roughly the same as Case B. Because power control tracks out the effect of rain, interference analysis can be simplified: we need consider either Case B or Case C but not both. Thus Case B is more conservative with imperfect power control; i.e., the turn-down will tend to be less than the fade margin, so the net received power at the victim receiver is several dB higher than Case C.

Case D is similar to Case C, except the interference is stray radiation from a sidelobe or backlobe of the SS antenna. In the worst case, the SS antenna sees rain towards its intended receiver and therefore does not turn down its power. Modeling of this case requires assumptions of the sidelobe and backlobe suppression of typical SS antennas. These assumptions need to take into account scattering from obstacles in the mainlobe path appearing as sidelobe emissions in real-world installations of SS antennas; an antenna pattern measured in a chamber is one thing while the effective pattern installed on a rooftop is another. If effective sidelobe and backlobe suppression exceeds the power turn down assumption for clear skies, then Case B dominates and Case D need not be considered. The only exception is where Case D models a source of interference that is not a fixed BWA system but a point-to-point transmitter or a satellite uplink. In these cases, the transmit parameters may be so different from a fixed BWA subscriber station that the interference could be significant.

Case E is another case of BS-to-BS interference. In this case, the interfering BS's main beam is in the victim's sidelobe or backlobe. In a related scenario, (not shown), the interfering BS's sidelobe is in the victim's main lobe. As fixed BWA systems tend to employ intensive frequency reuse, it is likely that Case A concerns will dominate over Case E.

Case F covers BS-to-BS backlobe-to-backlobe or sidelobe-to-sidelobe. The low gains involved here ensure that this is a problem only for co-deployment of systems on the same rooftop. Like all sources of BS-to-BS interference, this can be virtually eliminated in FDD via a coordinated band plan.

Case G covers interference from an SS antenna to the victim BS's sidelobe or backlobe. Referring to the commentary concerning Cases B and C, we need only consider the clear air case and assume the interferer has turned down its power. As BS antennas see wide fields of view, Case B is expected to dominate and Case G need not be considered.

Finally, **Case H** covers interference from a satellite downlink or stratospheric downlink. This case is not included in this Recommended Practice.With the above simplifying assumptions, the dominant sources of interference which require detailed modeling are shown in Figure 4.

Case A will tend to dominate unless there is a harmonized band plan for the use of FDD. It will be of concern for unsynchronized TDD or unharmonized FDD. Case B is always a concern. Case D is probably of less concern than Case B when the interferer is a fixed BWA system, but could be significant if the interferer is a higher-power point-to-point transmitter or satellite uplink. Case F is a concern only for co-sited BSs and can be largely mitigated by the use of a harmonized band plan with FDD.

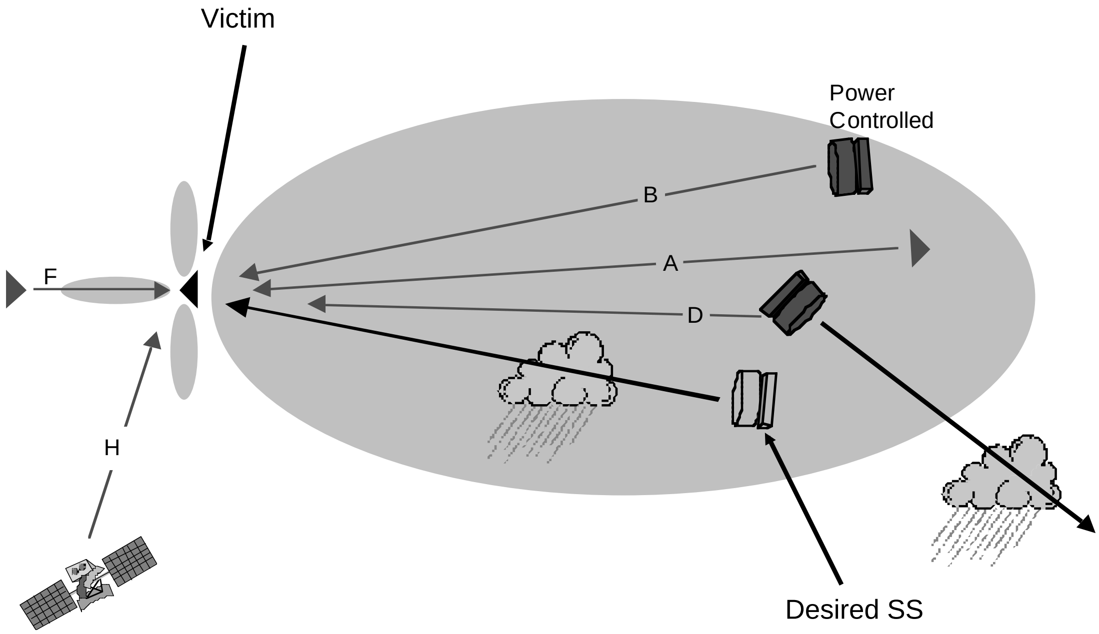


Figure 4—Simplified model for interference to a fixed BWA BS

5.3.1.3.2 Victim subscriber station

Figure 5 shows the main sources of interference to a subscriber station having a narrow beamwidth antenna.

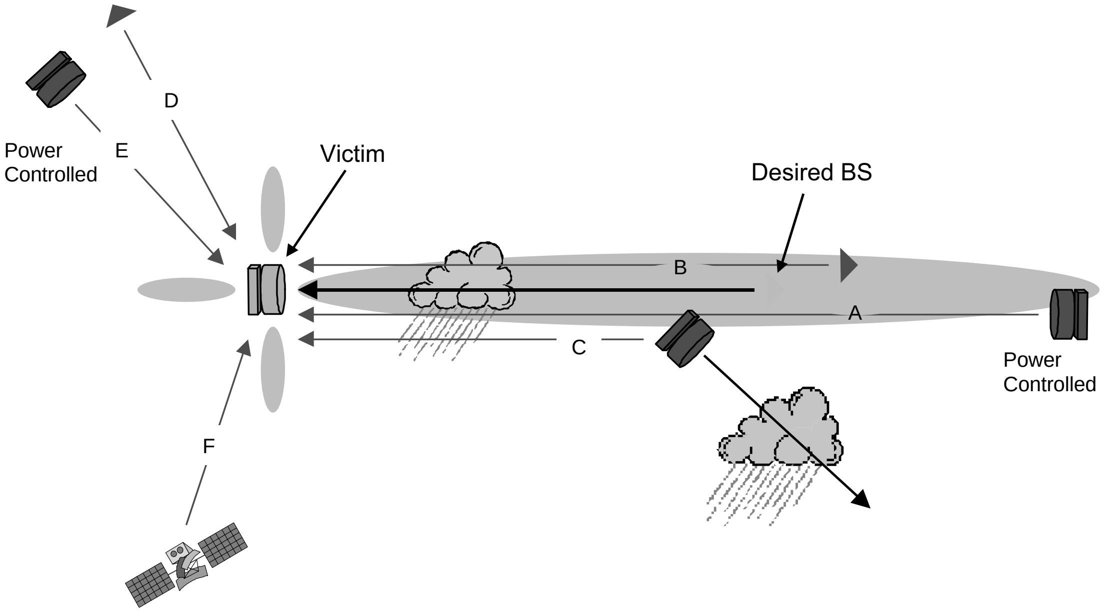


Figure 5—Interference sources to a fixed BWA subscriber station

The victim subscriber station is shown along with its radiation pattern (ellipses). The BS and several interferers are also shown. The victim SS cases are fundamentally different from the victim BS cases because the antenna pattern is very narrow. If the desired signal is assumed to be attenuated due to a rain cell, then interference arriving in the main lobe must also be assumed to be attenuated. The letters in Figure 5 illustrate several cases of interference to a subscriber station:

Case A covers SS-to-SS interference where the beams are colinear (which is relatively rare). In these cases, the interferer is generally far away from the victim; therefore, it may be assumed that the rain cell attenuating the interference as it arrives at the victim is not in the path from the interferer to its own BS. In this case, the interferer sees clear air and turns down its power.

Case B covers BS-to-SS interference.

Case C covers the case of a narrow-beam transmitter (fixed BWA or point-to-point) or satellite uplink at full power, due to rain in its path, but radiating from its sidelobe towards the victim. This case is more likely to occur than Case A because it could occur with any orientation of the interferer.

Case D covers BS-to-SS interference picked up by a sidelobe or backlobe of the victim. This case could be common because BSs radiate over wide areas, and this case could occur for any orientation of the victim.

Case E covers SS-to-SS interference picked up by a sidelobe or backlobe of the victim. Similar to reasoning in the victim BS cases B and C, the worst case can be assumed to be clear-air in the backlobe with the interferer having turned its power down.

Case F covers interference from a satellite downlink or stratospheric downlink. This case is not included in this Recommended Practice.

6. Equipment design parameters

This clause provides recommendations for equipment design parameters which significantly affect interference levels and hence coexistence. Recommendations are made for the following fixed BWA equipwment: base station equipment, subscriber station equipment, repeaters and intercell links (including PTP equipment). Recommendations are for both transmitter and receiver portions of the equipment design. The recommended limits are applicable over the full range of environmental conditions for which the equipment is designed to operate, including temperature, humidity, input voltage, etc.

NOTE—The following design parameters apply to Frequency Range 2 (23.5–43.5 GHz), unless otherwise indicated.

6.1 Transmitter design parameters

This subclause provides recommendations for the design of both subscriber and base station transmitters to be deployed in fixed broadband wireless access systems. Recommendations are also made for repeaters and intercell links.

6.1.1 Maximum EIRP spectral density limits

The degree of coexistence between systems depends on the emission levels of the various transmitters. Thus, it is important to recommend an upper limit on transmitted power, or, more accurately, a limit for the equivalent isotropically radiated power (EIRP). Since point-to-multipoint systems span very broad frequency bands and utilize many different channel bandwidths, a better measure of EIRP for coexistence purposes is in terms of *power spectral density* (psd) expressed in dBW/MHz rather than simply power in dBW.

The following paragraphs provide recommended EIRP spectral density limits. These limits apply to the mean EIRP spectral density produced over any continuous burst of transmission. (Any pulsed transmission duty factor does not apply.) The spectral density should be assessed with an integration bandwidth of 1 MHz; i.e., these limits apply over any 1 MHz bandwidth.

In preparing this Recommended Practice, emission limits from current (July 2000) US FCC (Part 101 section 101.113), Industry Canada (SRSP 324.25 12, SRSP 325.35 13, and SRSP 338.6 14), and ITU-R regulations and recommendations (ITU-R F.1509, 15, 17, and 18) were reviewed. Table 2 depicts some example regulatory EIRP spectral density limits.

Table 2—Comparison of typical regulatory and coexistence simulation EIRP spectral density values

Terminal	Example regulatory limits (dBW/MHz)	Simulation assumptions (dBW/MHz)
BS	+14	–1.5
SS	+30	+13.5
PTP	+30	+25.0
Repeater facing BS	+30	Not Performed
Repeater facing SS	+14	Not Performed
Mesh	+30	0

Although it is possible that the regulatory limits may be approached in the future, these emission limits are significantly higher (e.g., 15 dB) than supported by most currently available equipment. They are also significantly higher than those utilized by the coexistence simulations, which considered reasonable cell sizes, link budgets and availabilities and were the basis for the recommendations contained in this Recommended Practice. Table 2 compares regulatory limits to those used in simulations. Typical parameters used for the BS and in coexistence simulations for this Recommended Practice are as follows:

Tx Power:	+24 dBm (–6 dBW)
SS Antenna Gain:	+34 dBi
BS Antenna Gain:	+19 dBi
Carrier Bandwidth:	28 MHz (+14.47 dB-MHz)

It is recommended that any regulatory limits be viewed by the reader as future potential capabilities and that, where possible, actual deployments should use much lower EIRP spectral density values as suggested in 6.1.1.1 through 6.1.1.4. If systems are deployed using the maximum regulatory limits, they should receive a detailed interference assessment unless they are deployed in isolated locations, remote from adjacent operators. The assessment is needed to check consistency with the one guard channel recommendation for the same area/adjacent channel case (see Recommendation 7 in 4.2.7).

6.1.1.1 Base station (BS)

A BS conforming to the recommendations of this Recommended Practice should not produce an EIRP power spectral density exceeding +14 dBW/MHz. However, it is strongly recommended that a maximum EIRP power spectral density of 0 dBW/MHz be used in order to comply with the one guard channel recommendation for the same area/adjacent channel case (see Recommendation 7 in 4.2.7). The spectral density should be assessed with an integration bandwidth of 1 MHz; i.e., these limits apply over any 1 MHz bandwidth.

For the specific subband 25.25–25.75 GHz, the recommended BS EIRP spectral limits as stated in ITU-R F.1509 should be observed.

6.1.1.2 Subscriber station (SS)

A SS conforming to the recommendations of this Recommended Practice should not produce an EIRP spectral density exceeding +30 dBW/MHz. However, it is strongly recommended that a maximum EIRP power spectral density of +15 dBW/MHz be used in order to comply with the one guard channel recommendation for the same area/adjacent channel case (see Recommendation 7 in 4.2.7). Note the stated limits apply to the SS operating under faded conditions (rain attenuation). Power control is recommended for unfaded conditions, as described in 6.1.1.5.

NOTE—For the specific sub-band 25.25–25.75 GHz, the recommended SS EIRP limits as stated in ITU-R F.1509 should be observed and are summarized as follows:

Transmitter of an SS in a fixed BWA system or transmitters of point-to-point fixed stations: Where practicable, the EIRP spectral density for each transmitter of an SS of a fixed BWA system, or transmitters of point-to-point fixed stations in the direction of any geostationary (GSO) data relay satellite (DRS) orbit location specified in ITU-R Recommendation ITU-R SA.1276, should not exceed +24 dBW in any 1 MHz.

6.1.1.3 Repeater station

Several types of repeaters are possible (see 5.2). From the point of view of EIRP spectral density limits, two recommendations are given, according to the direction faced by the repeater and type of antenna used. The first recommended limit applies to situations where a repeater uses a sectored or omni-directional antenna, typically facing a number of SSs. The second case applies where a repeater uses a highly directional antenna, typically facing a BS or single SS.

Fixed BWA repeater stations systems deploying directional antennas and conforming to the equipment requirements of this Recommended Practice should not produce an EIRP spectral density exceeding +30 dBW/MHz. However, it is strongly recommended that a maximum EIRP power spectral density of +15 dBW/MHz be used in order to comply with the one guard channel recommendation for the same area/adjacent channel case (see Recommendation 7 in 4.2.7).

Fixed BWA repeater stations deploying omni-directional or sectored antennas and conforming to the equipment requirements of this Recommended Practice should not produce an EIRP spectral density exceeding +14 dBW/ MHz. However, it is strongly recommended that a maximum EIRP power spectral density of 0 dBW/MHz be used in order to comply with the one guard channel recommendation for the same area/adjacent channel case (see Recommendation 7 in 4.2.7).

6.1.1.4 In-band intercell links

An operator may employ point to point links that use adjacent channel or co-channel frequencies and that are in the same geographical area as a point to multipoint system. If the recommendations for SS EIRP in 6.1.1.2 and unwanted emissions in 6.1.3 are applied to these links, then they can operate within the coexistence framework described in this document. If not, then re-evaluation of the coexistence recommendations is recommended.

6.1.1.5 Uplink power control

A SS conforming to the equipment design parameters recommended by this Recommended Practice should employ uplink power control with at least 15 dB of dynamic range. Simulation results described in other sections of this document demonstrate that such a range is necessary in order to facilitate coexistence.

6.1.1.6 Downlink power control

This Recommended Practice assumes that no active downlink power control is employed. However, it is recommended that the minimum power necessary to maintain the links be employed. In all cases, the recommended limits given in 6.1.1 should be met.

6.1.2 Frequency tolerance or stability

The system should operate within a frequency stability of +/– 10 parts per million.

NOTE—This specification is only for the purposes of complying with *coexistence* requirements. The stability requirements contained in the air interface specifications may be more stringent, particularly for the base station. In addition, it is highly recommended that the SS transmit frequency be controlled by using a signal from the downlink signal(s).

6.1.3 Out-of-block unwanted emissions

Unwanted emissions produced by an operator's equipment and occurring totally within an operator's authorized band are relevant only for that operator and are not covered in this Recommended Practice. Unwanted emissions from an operator into adjacent bands should be constrained to avoid giving unacceptable interference to users of adjacent spectrum. Recommended emission limits are given below.

As indicated in Figure 6, single-carrier or multicarrier transmissions whose occupied bandwidth is totally within the authorized band will nevertheless emit some power into adjacent bands. These unwanted emissions include out-of-band (OOB) emissions (within 200% of the emission occupied bandwidth (B_0) of the authorized band edge) and spurious emissions (beyond this 200% point).

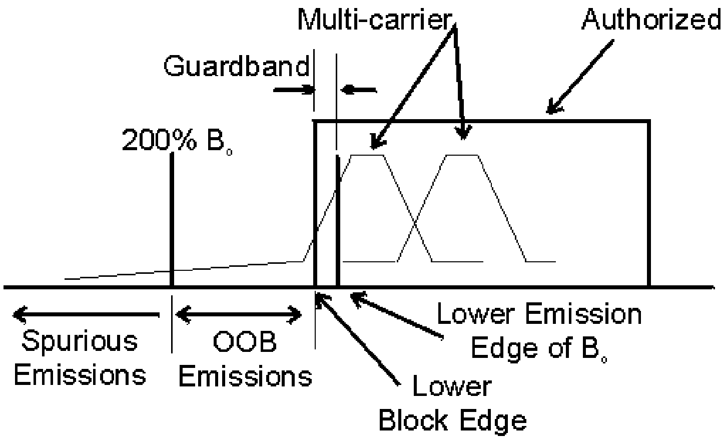


Figure 6—Unwanted emissions

The spectral density of unwanted emissions at the input to the antenna port should be attenuated by at least A (dB) below the total mean output power P_{mean} as follows:

1) For a single-carrier transmitter (see A.1.2, single-carrier test):

In any 1.0 MHz reference bandwidth outside the authorized band and removed from the authorized band edge frequency by up to and including +200% of the occupied bandwidth (i.e., $2\,B_o$), $A = 11 + 40\,f_{offset}/B_o + 10\,\log_{10}(B_o)$ (dB), where B_o is in MHz and f_{offset} is the frequency offset (in MHz) from the authorized band edge. Attenuation greater than $50 + 10\,\log_{10}(B_o)$ (dB) is not required. An absolute transmit level below –70 dBW/MHz is not required.

2) For a multicarrier transmitter or multitransmitters (excluding OFDM) sharing a common final stage amplifier (see A.1.3):

Each of the carriers individually should pass the single-carrier limit above and in addition the following limits apply:

The mask is to be the same as in 1), using the *occupied* bandwidth defined for multicarrier transmitters in 3.1. The total mean power is to be the sum of the individual carrier/transmitter powers.

NOTE—When several transmitters share a passive antenna, each transmitter should satisfy the individual mask; the multi-carrier mask should not be applied in this case.

3) In any 1.0 MHz band removed from the identified edge frequency by more than +200% of the occupied bandwidth:

Emissions should not exceed an absolute level of –70 dBW/MHz.

Figure 7 provides an example of how the unwanted emission mask would be applied to a hypothetical 50 MHz single carrier, located at the edge of the authorized band with a mean power of 0 dBW.

- The in-band spectral density will be $0 - \log_{10}(50) = -17$ dBW/MHz.
- The first section of the equation "$A = 11 + 40f_{offset}/B_o + 10\log_{10}(B_o)$" starts 11 dB below this in-band spectral density and falls linearly with offset frequency from the band edge
- In this example, the attenuation A reaches a value of –67 dB shortly before a 50 MHz offset and at that point the attenuation floor of "$A = 50 + 10\log_{10}(B_o)$" starts and continues at this value until a "$2B_o$" offset. In this example, the second adjacent channel attenuation is thus –50 dBc.
- Beyond the "$2B_o$" frequency offset, the spurious emission absolute limit of –70 dBW/MHz starts and continues out indefinitely.

In other examples (e.g., in the above example, if the mean power was –10 dBW), the absolute emission limit of –70 dBW/MHz may be reached before the attenuation floor of "$A = 50 + 10\log_{10}(B_o)$" is reached. In this case, the absolute emission limit takes precedence.

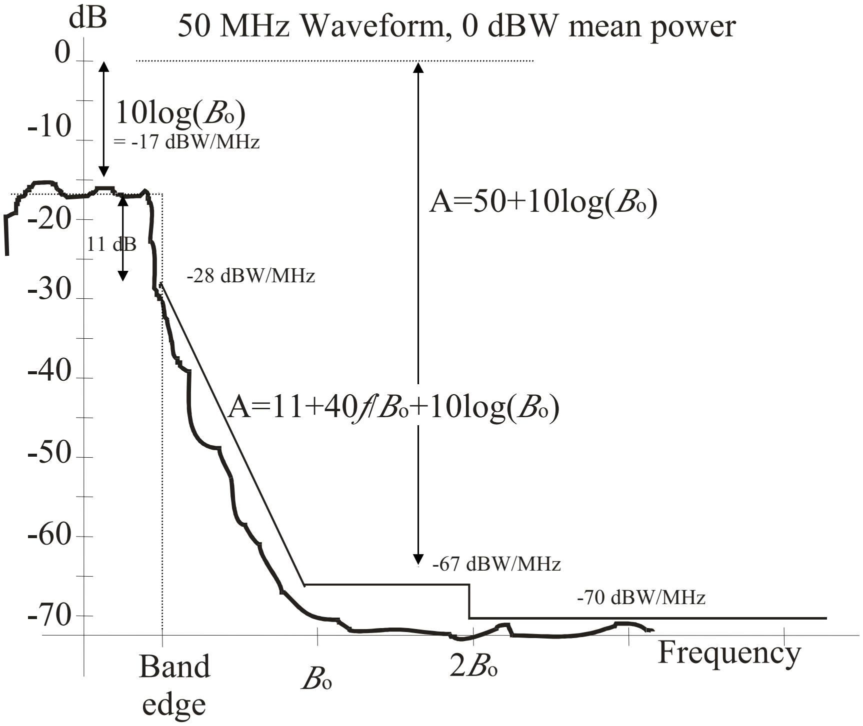


Figure 7—Example of application of unwanted emission limit

6.1.3.1 Unwanted emission levels specified in ETSI standards

In regions where they apply, the ETSI limits of EN 301 390 should be followed.

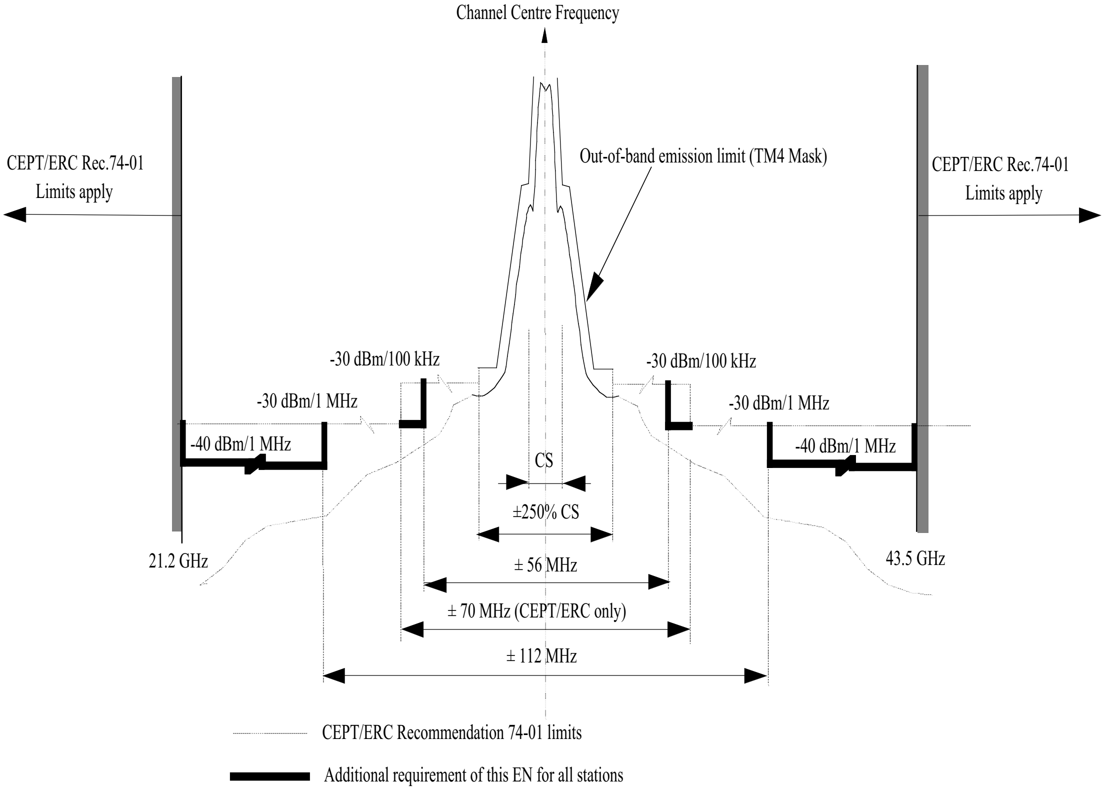
Within +/–250% of the channel, a specific spectrum mask applies. This should be taken from the appropriate standard documented by ETSI.

According to ETSI 301 390 section 4.1.3, the following requirements should be used in Europe:

The CEPT/ERC Recommendation 74-01 [B1] applies for spurious emissions in the frequency range 9 kHz to 21.2 GHz and above 43.5 GHz.

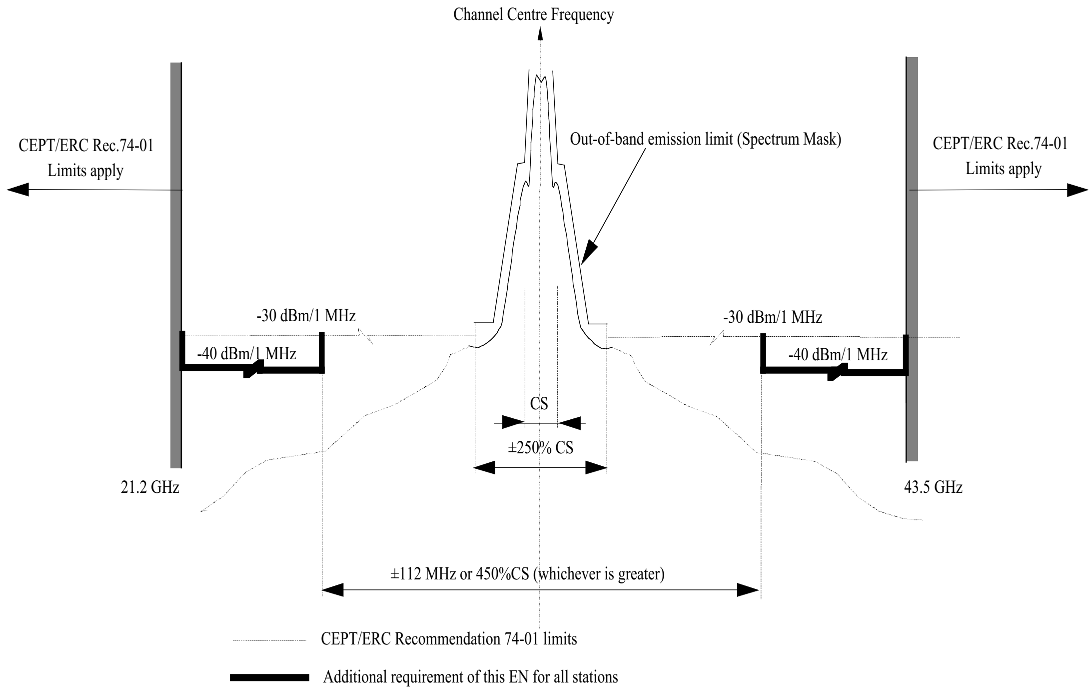
For spurious emissions falling in the range 21.2 GHz to 43.5 GHz, the tighter limits shown in Figure 8 and Figure 9 shall apply to both base and subscriber stations. In this frequency range, where the –40 dBm limit shown in Figure 8 and Figure 9 applies, allowance is given for no more than 10 discrete (CW) spurious emissions which are each permitted to exceed the limit up to –30 dBm.

In the same figures, for comparison, the less stringent limits from CEPT/ERC Recommendation 74-01 [B1] are also shown.



[*] In this figure, the abbreviation “CS” refers to “channel separation.”

Figure 8—Systems for channel separation 1 < CS* ≤ 10 MHz



[*] In this figure, the abbreviation “CS” refers to “channel separation.”

Figure 9—Systems for channel separation 1 < CS[*] ≤ 10 MHz

6.2 Antenna parameters

The following antenna parameters apply to Frequency Range 2 (23.5–43.5 GHz), unless otherwise indicated.

In considering coexistence, the operator needs to consider the antenna radiation pattern in the azimuth (AZ) and elevation (EL) planes relative to the required coverage footprint. For purposes of consistency and ease of implementation, the ability to select either horizontal or vertical polarization without the need for concern for differences in the RPEs is considered very important. Hence, the AZ and EL RPEs are independent of polarization. The polarization discrimination is specified in the tabular and graphical form below.

6.2.1 Polarization

Two linear polarization orientations, horizontal and vertical, are recommended. The required polarization purity is captured in the specification of antenna cross-polar discrimination (XPD) in 6.2.2. Also, the radiation pattern envelopes (RPEs) of this recommendation are independent of polarization.

6.2.2 Base station antenna

6.2.2.1 Electrical classes

The performance of BS antennas is here divided into two electrical classes. Class 1 represents the minimum recommended performance. Class 2 antennas have enhanced RPEs and represent more favorable coexistence performance.

a) Electrical Class 1

Electrical Class 1 antennas, which are characterized by moderate sidelobe performance, are recommended for operation in environments in which interference levels are typical.

b) Electrical Class 2

Electrical Class 2 antennas are meant for operation in environments in which interference levels could be potentially significant and cause problems under certain conditions.In such environments, Class 2 antennas with higher levels of discrimination in side lobes and back lobes may be deployed to provide acceptable performance of the system and mitigate intersystem interference.

6.2.2.1.1 Azimuth radiation pattern envelopes

This subclause describes radiation pattern envelopes (RPEs) for the two Electrical Classes of antenna.

The radiation pattern envelope is specified in terms of a variable α that is half the azimuth –3 dB beamwidth of the antenna. Sector sizes for these RPE tables range from 15^o to 120^o.

Figure 10 and Figure 11 illustrate the azimuth co-polar and cross-polar RPEs for the two electrical classes of antenna. Some specific data points are provided in Table 3 and Table 4; between these pint, linear interpolation is used.

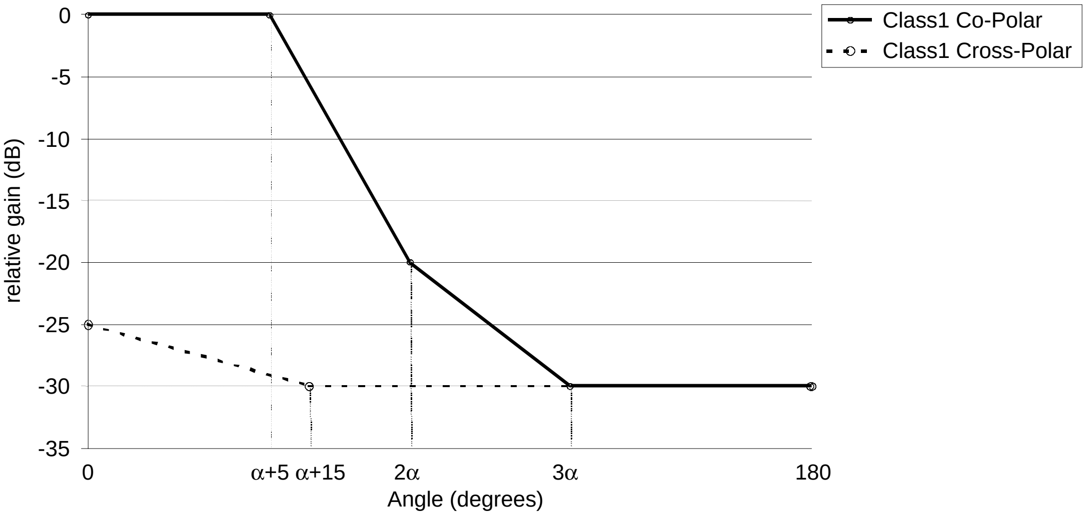


Figure 10—BS RPE in the azimuth plane—Electrical class 1

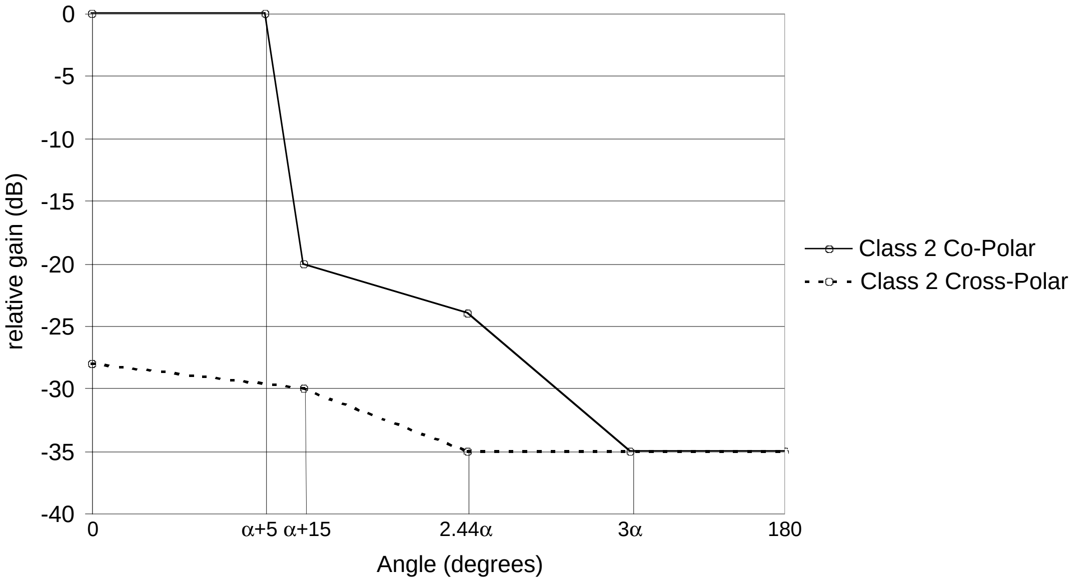


Figure 11—BS RPE in the azimuth plane—Electrical class 2

Table 3—BS RPE in the azimuth plane—Electrical Class 1

Angle (degrees)	Relative gain (dB)	
	Class 1 co-polar	**Class 1 cross-polar**
0	0	–25
α + 5	0	—
α + 15	—	–30
2α	–20	—
3α	–30	—
180	–30	–30

Table 4—BS RPE in the azimuth plane—Electrical Class 2

Angle (degrees)	Relative gain (dB)	
	Class 2 co-polar	**Class 2 cross-polar**
0	0	–28
α + 5	0	—
α + 15	–20	–30
2.44α	–24	–35
3α	–35	—
180	–35	–35

6.2.2.1.2 Elevation radiation pattern envelopes

The elevation RPEs should be specified both above and below the local horizon to provide isolation, improve coexistence, and ensure efficient use of radiated power. The pattern below the horizon should be specified as a minimum in order to reduce coverage nulls that would require an increase in radiated power by the SS antenna. The elevation RPE below the horizon is specified in terms of β, where 2β is the 3 dB beamwidth in the elevation plane.

This specification follows accepted practices for the specification of elevation radiation pattern envelopes that provide for the 0^o angle to be directed at the local horizon, the 90^o angle directed overhead, and the $–90^o$ angle directed downward.

It may be necessary in practical deployments to use electrical or mechanical tilt, or a combination of both, to achieve the required cell coverage, taking into account the surrounding terrain, for example.

Figure 12, Figure 13, and Figure 14 illustrate the elevation RPEs for Classes 1 and 2. Some specific data points are provided in Table 5, Table 6, and Table 7; between these points, linear interpolation is used.

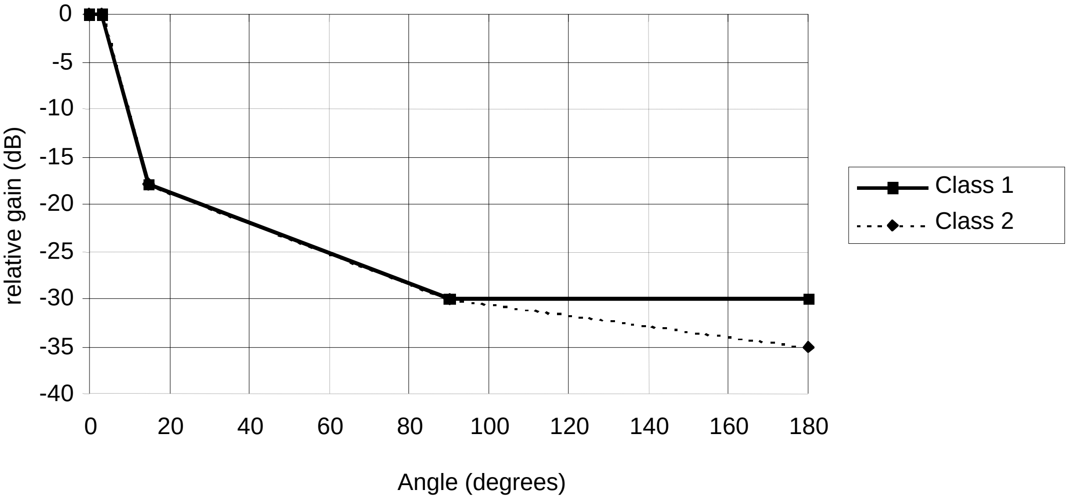


Figure 12—BS elevation co-polarized maximum above the horizon

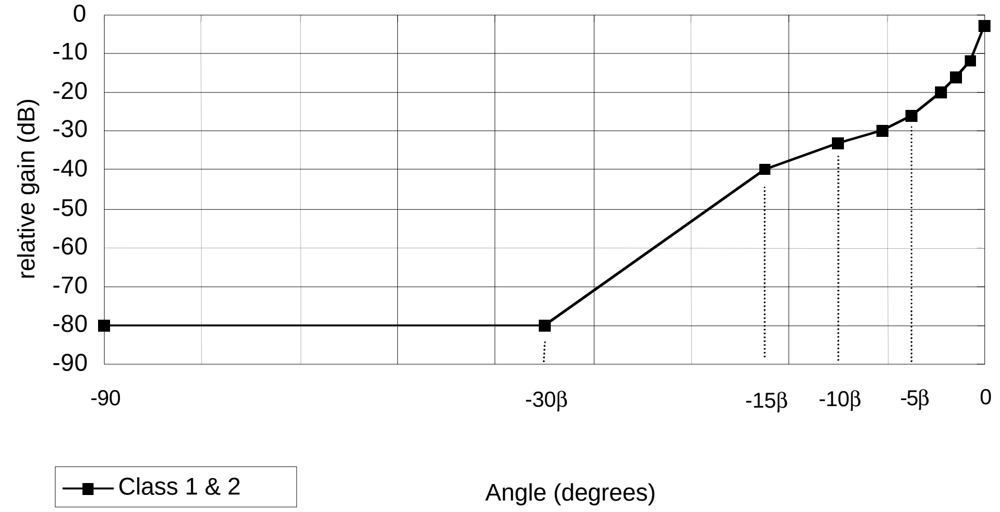


Figure 13—BS co-polarized minimum below the horizon

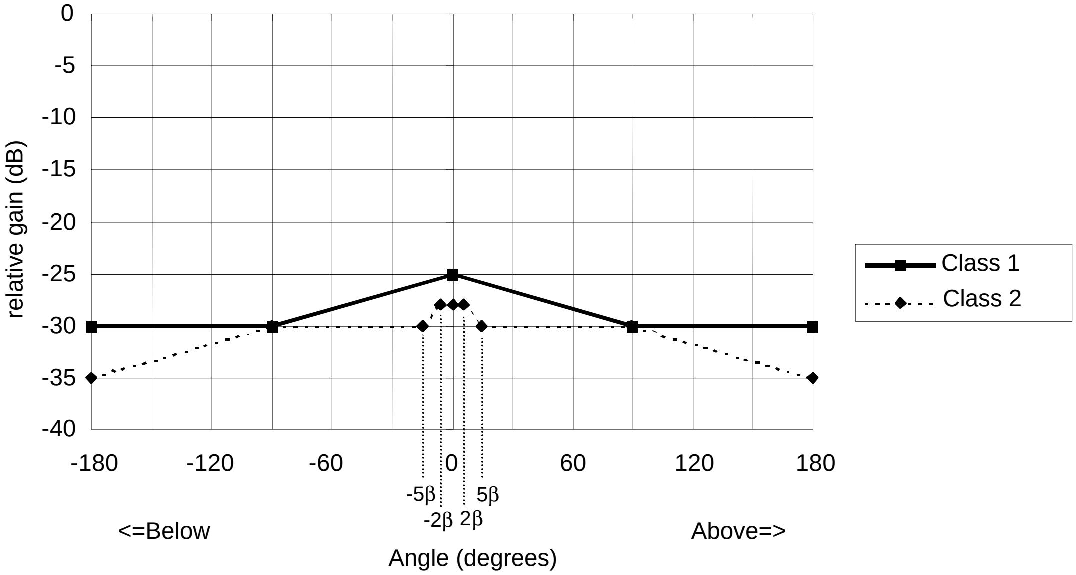


Figure 14—BS cross-polarized maximum above and below the horizon

Table 5—BS elevation co-polarized maximum above the horizon

Angle (degrees)	Relative gain (dB)	
	Class 1 co-polar	Class 2 cross-polar
0	0	0
β	0	0
15	–18	–18
90	–30	–30
180	–30	–35

Table 6—BS co-polarized minimum below the horizon

Angle (degrees)	Relative gain (dB)
	Class 1 & 2 co-polar minimum
0	–3
–β	–12
–2β	–16
–3β	–20
–5β	–26
–7β	–30
–10β	–33
–15β	–40
–30β	–80
–90	–80

Table 7—BS co-polarized minimum below the horizon

Angle (degrees)	Relative gain (dB)	
	Class 1 co-polar	Class 2 cross-polar
–180	–30	–35
–90	–30	—
–5β	—	–30
–2β	—	–28
0	–25	–28
2β	—	–28
5β	—	–30
90	–30	—
180	–30	–35

6.2.3 Subscriber station

Fixed BWA systems employ SS antennas that are highly directional, narrow-beam antennas. Although it is not as important for coexistence as the BS RPE, the RPE of the SS antenna is a factor in determining intersystem interference.

The performance of SS antennas is here divided into three electrical classes. Class 1 is defined with moderate sidelobe characteristics and represents the minimum recommended performance. Class 2 and Class 3 antennas have enhanced RPEs and represent increasingly favorable coexistence performance.

6.2.3.1 Radiation pattern envelope

Figure 15, Figure 16, and Figure 17 show the RPEs of co-polar and cross-polar patterns for Classes 1, 2, and 3. Some specific data points are provided in Table 8, Table 9, and Table 10; between these pint, linear interpolation is used.The required side lobe level and front-to-back ratio of the SS antenna depends on the coexistence scenario, *C/I* requirements of the radios, rain region, and f BS antenna pattern. It is recommended here that all of the above-mentioned parameters be taken into consideration in choosing the right class of antenna. In Table 8, Table 9, and Table 10, 2α is the 3 dB (or half-power) beamwidth of the antenna. It is also assumed that the same RPE should apply to both E-plane and H-plane. There is, however, no requirement on the symmetry of the antenna patterns as long as they meet the following RPEs.

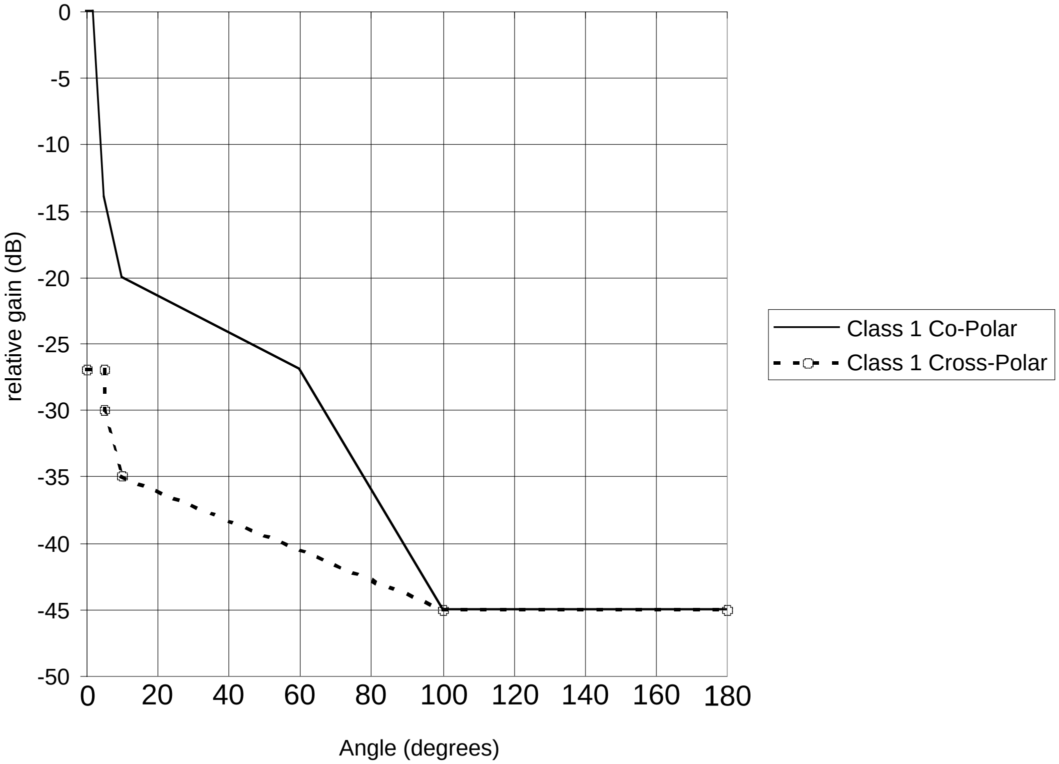


Figure 15—SS RPE Class 1

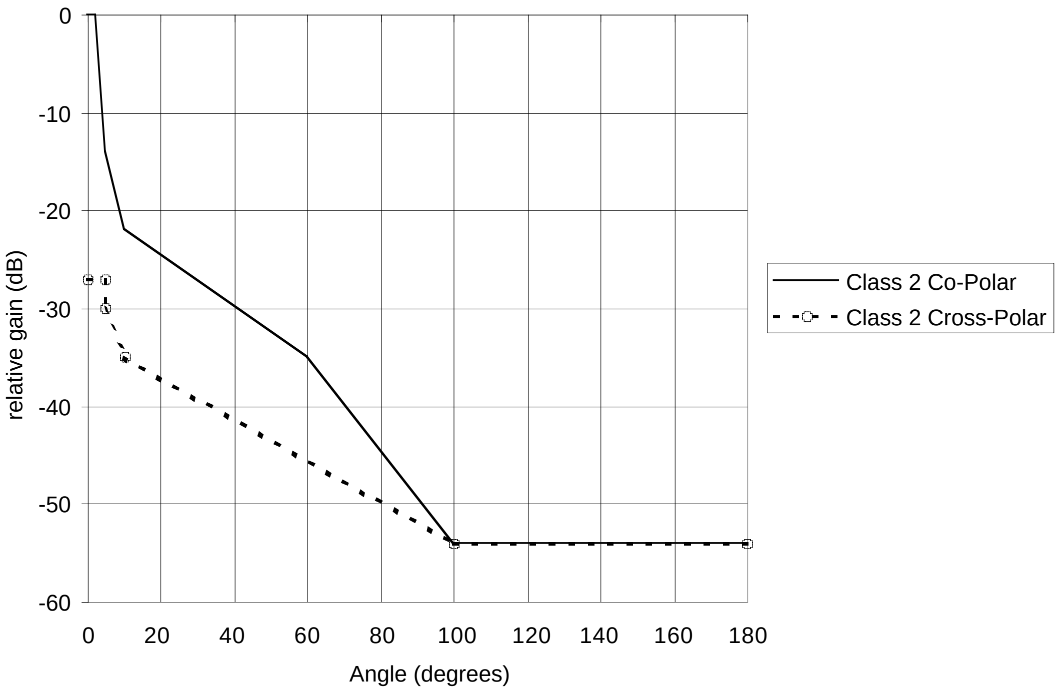


Figure 16—SS RPE Class 2

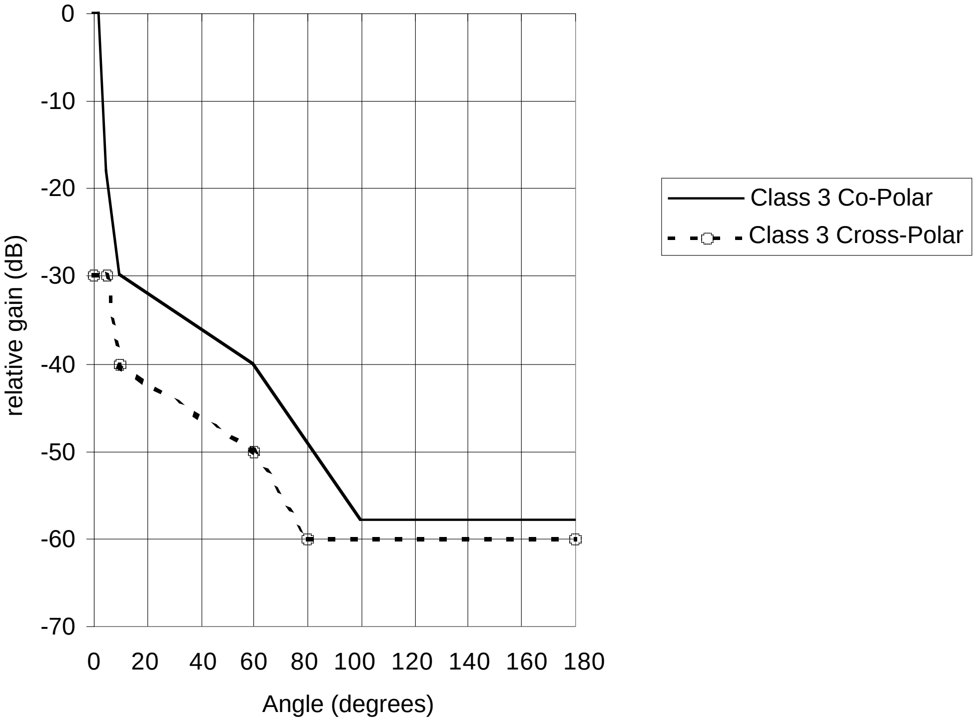


Figure 17—SS RPE Class 3

Table 8—SS RPE Class 1

Angle (degrees)	Relative gain (dB)	
	Class 1 co-polar	Class 1 cross-polar
0	0	–27
α	0	—
4.99	—	–27
5	–14	–30
10	–20	–35
60	–27	—
100	–45	–45
180	–45	–45

Table 9—SS RPE Class 2

Angle (degrees)	Relative gain (dB)	
	Class 2 co-polar	Class 2 cross-polar
0	0	–27
α	0	—
4.99	—	–27
5	–14	–30
10	–22	–35
60	–35	—
100	–54	–54
180	–54	–54

Table 10—SS RPE Class 3

Angle (degrees)	Relative gain (dB)	
	Class 3 co-polar	Class 3 cross-polar
0	0	–30
α	0	—
5	–18	–30
10	–30	–40
60	–40	–50
80	—	–60
100	–58	—
180	–58	–60

6.2.4 Mechanical characteristics

This subclause discusses the recommended minimum requirements regarding antenna mechanical requirements for typical environments. However, for harsher environments, such as hurricane-prone areas, more robust antenna systems may be required.

6.2.4.1 Wind and ice loading

Wind loading, as specified in this document for the BS, results in mechanical deformation or misalignment that would cause the radiated pattern to be altered and, hence, affect the coexistence characteristics. Antennas should meet the system operational requirements when subjected to the expected wind and ice loading in the geographical installation area. The angular deviation of the antenna main beam axis during specified operational conditions should not be more than 0.5^o. The antenna can exceed this deviation during survival conditions, but it should return to its original pointing direction after the adverse condition ceases. In any case, the minimum design operational wind load should be 112 km/hr, and the minimum design survival wind load should be 160 km/hr. These minimum specified loads may be increased substantially in many geographical areas. If potential ice buildup is a factor, the ice thickness should be considered radial, with the density assumed to be 705 kg/m^3. Consideration of ice buildup on the radome face depends on the material of the radome and whether a heater is utilized. Radome ice should be considered on a case-by-case basis

6.2.4.2 Water tightness

Water tightness is important in eliminating unwanted attenuation that might be nonuniform over the antenna aperture. This could change the pattern and nonuniformly reduce the distance over which the BS would operate. In this regard, the antenna should be designed to ensure that water ingress is negligible.

6.2.4.3 Temperature and humidity

The antennas should not suffer performance degradation when subjected to temperature or humidity extremes, as this could potentially cause interference. Therefore, antennas should be designed to operate within the recommendation of this document over the full temperature and humidity range for which the system is intended to be deployed.

6.2.4.4 Radomes and heaters

If radomes are used, all recommended antenna limits included in this Recommended Practice should be metiers the radomes installed. This includes radome heaters where required.

6.2.4.5 Labeling

With respect to coexistence, labeling aids in installing the correct antenna with the correct radiation characteristics. Antennas should be clearly identified with a weatherproof and permanent label(s) showing the antenna type, antenna frequency range, antenna polarization, and serial number(s). It should be noted that integrated antennas may share a common label with the outdoor equipment.

6.2.4.6 Mechanical adjustment assembly

The sector antennas described in this specification typically have a wide azimuth pattern and a narrow elevation pattern. The mechanical tilting assembly should accommodate adjustments in elevation and azimuth, consistent with the overall system design requirements.

6.2.4.7 Vibration

Due to narrow azimuth and elevation beamwidth, the SS antennas should be highly stable and undergo little mechanical deformation due to wind and other sources of vibrations.

6.3 Receiver design parameters

This subclause provides recommendations for the design of both subscriber and base station receivers, which are to be deployed in fixed broadband wireless access systems. The parameters for which recommendations are made are those that affect performance in the presence of interference from other fixed BWA systems.

6.3.1 Co-channel interference tolerance

The simulations performed in support of the recommendations included in this Recommended Practice assume an interference signal level not exceeding 6 dB below the receiver noise floor causing a noise floor degradation of 1 dB. This was chosen as an acceptable degradation level upon which to operate a fixed BWA system while allowing interference levels to be specified in an acceptable manner. The following subclauses recommend minimum design standards to allow for interference.

These simulations do not account for an operator's specific equipment and frequency band. Operators should adjust the results to account for their own system parameters.

6.3.1.1 Base station

The base station receiver might be subjected to adjacent channel interference and co-channel interference from other fixed BWA systems operating in close proximity to the reference system. Therefore, the base station receivers should be designed with proper selectivity and tolerance to interference.

6.3.1.2 Subscriber station

The SS receiver might be subjected to adjacent channel interference and co-channel interference from other fixed BWA systems operating in the close proximity to the reference system. Therefore, the receivers intended for SS terminal applications should be designed with the proper selectivity and tolerance to interference.

6.3.1.3 Link availability in a joint *C/N* + *C/I* transmission environment

From the simulation results described in other sections of this document, it has been found that some single interference coupling is usually dominant when worst case interference levels are examined. Such worst case impairments are expected to be rare as they require a boresight alignment between interference and victim antennas.

The simulation results indicate that the proposed receiver interference tolerance of a 1 dB threshold impairment is sufficient in terms of establishing acceptable coordination design objectives. However, the possibility still remains that multiple interferers can exist and may add to the threshold impairment. The following example examines the significance of these interference sources.

The system design model is based on the "typical" parameters for fixed BWA at 26 GHz as identified in 6.1.1. A 4-QAM modulation system is assumed with an excess bandwidth of 15% and a receiver noise figure of 6 dB. Availability objectives of 99.995% for a BER = 10^{-6}, based on a threshold $C/N = 13$ dB, translate to a maximum cell radius of $R = 3.6$ km in ITU-R rain region K with a corresponding interference-free fade margin of 26 dB. Worst case H-POL transmission has been assumed.

For $I/N = -6$ dB, $C/I = 19$ dB and the effective receiver threshold is impaired by approximately 1 dB such that the limiting C/N is now 14 dB. A 3 dB impairment to threshold ($C/I = 16$ dB) would move the C/N requirement to 16 dB. Figure 18 illustrates the reduction in availability as C/I increases, referenced to R fixed at 3.6 km. It is apparent that link availability degrades modestly as C/I increases. At $C/I = 16$ dB, availability has degraded to only 99.9925%.

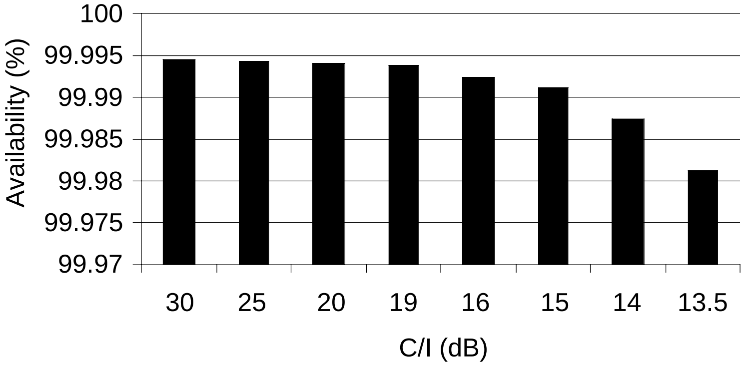


Figure 18—Availability versus *C/I* for a fixed cell radius R=3.6 km

Figure 19 indicates the necessary reduction in cell radius R that would be required to maintain availability at 99.995%. At *C/I* = 16 dB, R is reduced to 3.25 km, a reduction of 10%. Consequently, if system operation in a strong interference environment is anticipated, a system design with modestly reduced cell dimensions may be prudent.

It is thus concluded that the selected *I/N* = –6 dB is a conservative metric for specification of interference criteria.

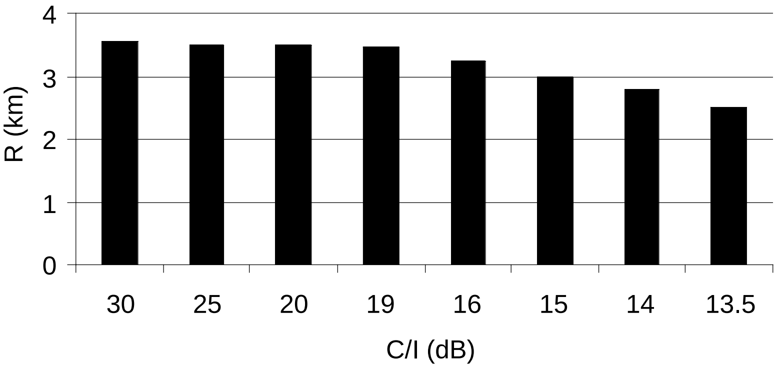


Figure 19—Radius versus *C/I* for a fixed availability of 99.995%

6.3.2 Adjacent channel desired to undesired signal level tolerance

Where coordination between operators cannot be guaranteed, it is recommended that an operational receiver be capable of withstanding the exposure of relatively high power adjacent channel carriers. The recommended numerical values below are based on the emission mask in 6.1.3, QPSK modulation and, single-carrier operation. Coordination between operators will reduce the likelihood of this kind of interference.

This recommendation has a direct impact on coexistence referenced to the estimation of guard band requirements discussed extensively elsewhere in this Recommended Practice. The coexistence criteria assume that adjacent channel carrier interference, as defined by net filter discrimination (NFD), establishes the requirements and that interfering signals have not degraded the NFD. Thus, the following tests can be only indirectly related to the emission level masks and the guard band criteria recommended elsewhere in this Recommended Practice.

A possible test can be defined in terms of a desired carrier (*D*) to undesired carrier (*U*) ratio, *D/U*. The *D* carrier emissions should correspond to the signal characteristics normally expected to be present at the victim receiver input port.

6.3.2.1 Base station and subscriber station *D/U* tolerance

This test should be performed with both desired and undesired signals having the same modulation characteristics and equal transmission bandwidths. With both the desired *D* and undesired *U* signals coupled to the input of the victim *D* receiver, set the input level of the desired signal such that it is 3 dB above the nominally specified BER performance threshold.

6.3.2.1.1 First adjacent channel *D/U*

Set the undesired carrier frequency so that it corresponds to a one channel bandwidth frequency offset and at a $D/U = -5$ dB.

The measured BER performance of the *D* receiver should not exceed that specified for nominal threshold performance.

6.3.2.1.2 Second adjacent channel *D/U*

Set the undesired carrier frequency so that it corresponds to a two channel bandwidth frequency offset and at a $D/U = -35$ dB.

The measured BER performance of the *D* receiver should not exceed that specified for nominal threshold performance.

Examples of suitable test methods can be found, such as those in ETSI conformance testing procedures (see A.3).

Where coordination between operators cannot be guaranteed, it is recommended that an operational receiver be capable of withstanding the exposure of relatively high power adjacent channel carriers.

7. Deployment and coordination

This clause provides a recommended structure process to be used to coordinate deployment of fixed BWA systems in order to minimize interference problems.

NOTE—National regulation and/or international agreements may impose tighter limits than the following and shall take precedence in this case.

This methodology will facilitate identification of potential interference issues and, if the appropriate recommendations are followed, will minimize the impact in many cases, but compliance with this process will not guarantee the absence of interference problems.

NOTE—In the following, “coordination” implies, as a minimum, a simple assessment showing the likelihood of interference. It may imply a detailed negotiation between operators to mitigate problem areas for the benefit of both systems.

7.1 Co-frequency/adjacent area

7.1.1 Methodology

Coordination is recommended between licensed service areas where both systems are operating co-channel, i.e., over the same fixed BWA frequencies, and where the service areas are in close proximity, e.g., the shortest distance between the respective service boundaries is less than 60 km.[7] The rationale for 60 km is given in 7.1.2. The operators are encouraged to arrive at mutually acceptable sharing agreements that would allow for the provision of service by each licensee within its service area to the maximum extent possible.

Under the circumstances where a sharing agreement between operators does not exist or has not been concluded, and where service areas are in close proximity, a coordination process should be employed. In addition to the procedure described below, two alternative coordination procedures are described in Annex E (based on a different *I/N*) and Annex F (based on a two-tier psfd approach).

Fixed BWA operators should calculate the power spectral flux density (psfd) at their own service area boundary. Power spectral flux density should be calculated using good engineering practices, taking into account such factors as propagation loss, atmospheric loss, antenna directivity toward the service area boundary, and the curvature of Earth. The psfd level at the service area boundary should be the maximum value for elevation point up to 500 m above local terrain elevation. No aggregation is needed because principal interference processes are direct main beam to main beam coupling. Refer to 7.1.2 for a rationale behind the psfd levels presented in this process. The limits here refer to an operator's own service boundary, since that is known to the operator and will frequently be the same as the adjacent operator's service boundary. In cases where the two boundaries are separate (e.g., by a large lake), dialog between operators, as part of the coordination process, should investigate relaxing the limits by applying the limits at the adjacent service boundary. In cases where there is an intervening land mass (with no licensed operator) separating the two service areas, a similar relaxation could be applied. However, in this case, caution is needed since both existing operators may have to re-engineer their systems if service later begins in this intervening land mass.

Deployment of facilities which generate a psfd, averaged over any 1 MHz at their own service area boundary, less than or equal to that stated in Table 11, should not be subject to any coordination requirements.

Table 11—Maximum psfd limits

Frequency band	psfd (dBW/m^2)/MHz
24, 26, 28 GHz	–114
38, 42 GHz	–111

7.1.2 Coordination trigger

As described above, distance is suggested as the first trigger mechanism for coordination between adjacent licensed operators. If the boundaries of two service areas are within 60 km of each other, then the coordination process is recommended.

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[7] In case of sites of very high elevation relative to local terrain, BWA service areas beyond 60 km may be affected. The operator should coordinate with the affected licensee(s).

The rationale for 60 km is based upon several considerations, including radio horizon calculations, propagation effects, and power flux density levels. The latter is discussed in 7.3.

The radio horizon, defined as the maximum line-of-sight distance between two radios, is defined (see Figure 20) as follows:

$$R_h = 4.12(\sqrt{h_1} + \sqrt{h_2}) \tag{1}$$

where

R_h = radio horizon (km)
h_1 = height of Radio 1 above clutter (m)
h_2 = height of Radio 2 above clutter (m)

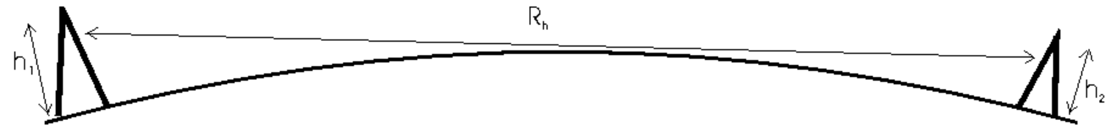

Figure 20—Geometry of radio horizon

Table 12 presents the horizon range for different radio heights above average clutter. Note that if the antenna is erected on a mountain (or building), then the “height of radio above clutter” will probably also include the height of the mountain (or building).

Table 12—Horizon range for different radio heights AGL (in kilometers)

Height of Radio 2 above clutter (m)	Height of Radio 1 above clutter (m)								
	10	20	30	40	50	60	70	80	90
10	26	31	36	39	42	45	47	50	52
20	31	37	41	44	48	50	53	55	58
30	36	41	45	49	52	54	57	59	62
40	39	44	49	52	55	58	61	63	65
50	42	48	52	55	58	61	64	66	68
60	45	50	54	58	61	64	66	69	71
70	47	53	57	61	64	66	69	71	74
80	50	55	59	63	66	69	71	74	76
90	52	58	62	65	68	71	74	76	78

The worst-case interference scenario involves two base stations, as these are typically located on relatively high buildings or infrastructures and hence have greater radio horizon distances than subscriber stations. A typical height for a base station is 65 m above ground level, or 55 m above clutter, assuming an average clutter height of 10 m over the whole path length. This produces a radio horizon of 60 km. There will be cases where the base station equipment may be located on higher buildings, which would produce a greater radio horizon. However, these base stations tend to tilt their antennas downward. This effectively reduces the amount of power directed towards the adjacent base station and therefore reduces the interference. The following subclauses examine power levels in further detail.

7.2 Same area/adjacent frequency

As stated in Recommendation 7 (4.2.7), deployments will usually need one guard channel between nearby transmitters. Where administrations do not set aside guard channels, the affected operators would need to reach agreement on how the guard channel is apportioned between them. Where channel sizes are different, the guard channel should be equal to that of the wider channel system. This document does not consider the case where an operator deploys multiple channel sizes within his or her allocation.

7.3 Use of power spectral flux density (psfd) as a coexistence metric

This subclause addresses the maximum power flux density that can be tolerated as a result of co-channel interference originating from an adjacent licensed operator. For the purposes of the Recommendations in this document, the amount of interference generally considered acceptable or tolerable is a level which produces a degradation of 1 dB to the system's *C/N* This degradation is usually taken into consideration during the original link budget exercise. For the noise floor to increase by 1 dB, the interference power level must be 6 dB below the receiver's thermal noise floor.

In Annex B, a typical psfd calculation is shown at frequencies of 28 and 38 GHz. The psfd limit can be applied in different ways that affect the probability of interference. Two examples are given in Annex A and Annex F.

The 38 GHz band has been used extensively for individual point-to-point radio links for a number of years in many countries. More recently, the band has also been used to provide point-to-point links in support of fixed broadband wireless access systems. Thus, it is important that these point-to-point radio receivers be afforded an equal opportunity to coexist with point-to-multipoint equipment in a shared frequency environment. Where there is significant deployment of point-to-point links as well as point-to-multipoint systems and protection of point-to-multipoint systems is mandated, tighter psfd trigger levels may be appropriate [e.g., –125 (dBW/m^2)/MHz at 38 GHz band is applied by some administrations to protect point-to-point links].

7.4 Deployment procedure

Operators should develop a "turn-on" procedure for use during transmitter activation, the objectives being the avoidance of inadvertent interference generation. The "turn-on" operator is highly encouraged to communicate with other known operators who may be affected. It is expected that operators will independently develop their "turn-on" procedures but it is outside the scope of this document to provide specifics.

8. Interference and propagation evaluation/examples of coexistence in a PMP environment

8.1 Guidelines for geographical and frequency spacing between fixed BWA systems

The following subclauses indicate some of the models, simulations, and analysis used in the preparation of this Recommended Practice. While a variety of tools can be used, it is suggested that the scenarios studied below be considered when coordination is required.

8.1.1 Summary

This subclause provides guidelines for geographical and frequency spacings of fixed BWA systems that would otherwise mutually interfere. The guidelines are not meant to replace the coordination process described in Clause 7. However, in many (probably most) cases, by following these guidelines, satisfactory psfd levels will be achieved at system boundaries. The information is therefore valuable as a first step in planning the deployment of systems.The actual psfd levels can then be calculated or measured, as appropriate, and any adjustments to system layout can then be made. These adjustments should be relatively small, except in unusual cases.

8.1.2 Interference mechanisms

Various interference mechanisms can reduce the performance of fixed BWA systems. Although intrasystem interference is often a significant source of performance degradation, it is not considered in this analysis. Its reduction to acceptable levels requires careful system design and deployment, but these are under the control of the operator, who may decide what constitutes an acceptable maximum level. Thus, only intersystem interference mechanisms, where interoperator coordination may be appropriate, are considered here. In each frequency band assigned for fixed BWA use, different types of systems may be deployed, some conforming to IEEE 802.16 standards and some designed to other specifications. Therefore, we consider a wide range of possibilities in determining the likely interference levels and methods for reduction to acceptable levels.

The following are the two main scenarios, each with several variants:

- Co–channel systems that are geographically spaced
- Systems that overlap in coverage and (in general) require different frequencies of operation

The various potential BS-SS-RS interference paths need to be considered to determine how much interferwence will occur. Between any two systems, several interference mechanisms may be operating simultaneously (see 5.3). The geographical or frequency spacing (or both) necessary to reduce interference to acceptable levels is then determined by the most severe mechanism that occurs.

A number of techniques have been used to estimate intersystem interference. They are as follows:

- Worst case analysis
- Interference Area method
- Monte Carlo simulations

Each of these is described below. The most appropriate method depends on the interference mechanism. In each case, geographical or frequency spacing between systems has been varied in the calculations until the interference is below an acceptable threshold. These values are shown in the tables of results as guidelines for nominal geographical or frequency spacing.

8.1.3 Worst-case analysis

Some interference mechanisms arise from a single dominant source and affect each victim in a similar way. A relatively simple calculation of the worst-case interference can then be made, using realistic values for system parameters and ignoring additional radio path terrain losses. An example is the interference from a single dominant BS into the victim BS of an adjacent system.

8.1.4 Simulations

There are many cases where a simple worst-case analysis is of limited use. Where there are many possible interference paths between a particular type of interferer and the associated victim stations, the worst case could be very severe, but may also be very improbable. Planning on the basis of the worst case would then be unrealistic. An example is the interference between subscriber stations of different operators in the same geographical area. Most interference will be negligible, but a certain small proportion of cases could have very high interference levels. Monte Carlo simulations provide a means of assessing the probability of occurrence of a range of interference levels at victim stations. The recommended geographical or frequency spacing is then a compromise in which an acceptably small proportion of cases suffer interference above the recommended limit. For example, 1% of randomly positioned SSs might suffer interference above the desired level. A model of an interference scenario is created using realistic parameters in which the placement of fixed BWA stations (usually the SSs) can be randomly varied. Other randomly varied parameters, such as buildings and terrain factors, may be included. The simulation is run many times and the results plotted as a probability distribution.

8.1.5 Interference area (IA) method

In some scenarios, it can be shown that specific parts of the coverage area will suffer high levels of interference while other areas are not affected. The interference area (IA) is the proportion of the sector coverage area where interference is above the target threshold. This is equivalent to the probability that a randomly positioned station (within the nominal coverage area) will experience interference above the threshold. In several scenarios, the interference area value is a small percentage and the locations are predictable. Although high levels of interference do occur, they are sufficiently localized to be acceptable.

The interference area may be determined by running a simulation program in which victim or interfering stations are randomly positioned. For each case in which the desired interference limit is reached or exceeded, a point is marked on a diagram. After a large number of trials, the interference area value can be calculated and is easily identified on the diagram. Figure C.5 provides an example.

8.1.6 ISOP (Interference scenario occurrence probability)

Although not used in this document, the concept of ISOP may be interesting in some cases. The ISOP analysis is an extension of the IA method in which a calculation is made of the probability that at least one victim SS will be inside the IA. The probability may be averaged across a wide range of different frequency and polarization assignment cases and therefore may not be representative of a specific deployment.

Further information on both the ISOP method and the IA method can be found in ERC Report 099 [B2].

8.1.7 Simulations and calculations

Table 13 summarizes the simulations and calculations undertaken for this Recommended Practice. The most appropriate method has been selected, dependent on the scenario and interference path.

Table 13—Summary of the simulations and calculations

Path (note 1)	FDD or TDD	Scenario	Method	Spacing at which simulation results have shown the interference to be generally below target level (Note 1)
SS to BS	FDD/TDD	Adjacent area, same channel	Monte Carlo simulation	40 km BS-BS (different system)
BS to SS	FDD/TDD	Same area, adjacent channel(s)	Monte Carlo simulation	1 guard channel (Note 3)
SS to BS	FDD/TDD	Same area, adjacent channel	Monte Carlo simulation	1 guard channel (Note 3)
BS to SS	FDD/TDD	Same area, adjacent channel	Interference Area (IA)	1 guard channel = 0.5–2% IA (Note 3)
BS to BS	FDD/TDD	Same area, adjacent channel	Monte Carlo simulation	1 guard channel (Note 3)
SS to SS	TDD	Same area, adjacent channel	Monte Carlo simulation	1 guard channel (Note 3)
SS to SS	TDD	Adjacent area, same channel	Monte Carlo simulation	Low probability if BS-BS >35 km (different system)
SS to BS	FDD/TDD	Adjacent area, same channel	Interference Area (IA)	35 km BS-BS (different system)
BS to BS (multiple interferers)	FDD/TDD	Adjacent area, same channel	Monte Carlo simulation	60 km (Note 4)
Mesh to PMP BS	FDD /TDD	Adjacent area, same channel	Monte Carlo Simulation	12 km BS to mesh edge
Mesh to PMP SS	FDD /TDD	Adjacent area, same channel	Monte Carlo Simulation	Low probability if mesh edge to BS > 12 km
Mesh to PMP BS	FDD/TDD	Same area, adjacent channel	Monte Carlo Simulation	1 guard channel (Note 5)
Mesh to PMP SS	FDD/TDD	Same area, adjacent channel	Monte Carlo Simulation	1 guard channel (Note 5)

NOTES

1—While the target level of interference is generally referenced to a level which is 6 dB below the receiver noise floor, in many scenarios the acceptability of the spacing guideline requires assessment of the results of a statistical analysis and the acceptability of a small percentage of instances when this target level is exceeded.

2—All scenarios represent interference paths between two different PMP systems, unless otherwise stated.

3—The single guard channel result is derived from an analysis in which the channel size of interfering and victim stations is the same. Where channel spacings are considerably different across the frequency block boundary, analysis suggests that one equivalent guard channel may be necessary at the edge of each operator's block.

4—The results from the multiple BS interference simulation are based on an adverse terrain assumption and on the use of omni-directional BS antennas. The victim BS is assumed to be at a high location, with clear line of sight to all interfering BSs. Results taking account of terrain and building losses and sectored BS antennas are for future analysis.

5—The single guard channel is a conservative figure. Even with zero guard channels, a large proportion of simulation runs produced much lower interference than the desired threshold. Thus, by careful design or by use of intelligent interference mitigation, the guard channel could be reduced or eliminated.

8.1.8 Variables

In the simulations, a number of parameters have been varied in order to test the sensitivity of the results to critical aspects of system design. In particular, antennas with various RPEs have been evaluated. In particular, simulations have been completed using data for antennas with a range of RPEs. While many of the simulation results show improvement with the use of antennas with enhanced RPEs, the relative value of the performance improvement was found to be modest for all of the antennas considered. On this basis, a good practice is to choose the best antenna possible, consistent with system economics.

In some configurations, the intrasystem interference considerations will dominate the decision on antenna RPEs. Effective frequency reuse between cells will demand the use of antennas whose intrasystem requirements can provide satisfactory intersystem interference levels.

8.1.9 Results of the analysis

Simulations have been undertaken for many of the interference mechanisms described below. A summary of each method and its results is given in Annex C.

8.1.10 Co-channel case

8.1.10.1 BS-to-BS co-polar, single, and multiple interferes

This scenario only occurs where the victim BS receiver is co-channel to the interfering BS transmitter. The BS-to-BS interference is not necessarily the worst case, but when interference occurs, it affects a large number of users at the same time. Mitigation, by moving or repointing the BS or by changing frequency, can be very disruptive to a system. Therefore, a relatively “safe” value should be applied to co- channel, co-polar geographical spacing. Shorter distances are possible, but will increase the probability of interference. Therefore it is recommended that these be verified by more detailed analysis.

Occasionally, the normal recommended geographical spacing will not be sufficient, due to adverse terrain conditions. Where one station is on a local high point much higher than the mean level of the surrounding terrain, it is recommended that a specific calculation or measurement be made of the interference level and the necessary geographical spacing derived from this.

The results for this case are derived from worst-case analysis (for a single interferer and a typical set of system parameters) and from simulation. This analysis has used parameters that are typical of fixed BWA systems.

For systems with multiple BSs, typical frequency reuse arrangements can lead to multiple sources of interference on a given channel/polarization. The level of interference can therefore be higher than that for a single interferer.

8.1.10.2 SS-to-BS, co–channel case

In this case, single and multiple SSs need to be considered. Depending on the system design, the number of SSs which transmit at any one time may be low (or only one) from a given cell sector. However, interference can often arise from several cells, especially when rain fading occurs selectively (i.e., where a localized storm cell attenuates some radio paths but not others).

In the case of mesh systems, there may be several interferers on a given channel, although only a small number will transmit simultaneously and very few will be visible at a particular BS simulation. Monte Carlo modeling may be useful to analyze this case of multiple interferers.

8.1.10.3 SS-to-SS, co-channel case

Interference between SSs in adjacent areas has, in general, a low probability of occurrence. In PMP systems, it usually occurs in specific areas. Its level could be low or high, depending on circumstances. If co-channel PMP cells are at or beyond the minimum recommended “safe” distance, SS interference has a low probability, but in a few cases (in localized interfered areas) could be at a higher level than that experienced by a BS due to the higher antenna gain of the subscriber station.

For the mesh to PMP case, the results are similar to PMP to PMP, except that interference is generally lower, due to the use of lower gain mesh SS antennas.

8.1.11 Overlapping area case

In the overlapping area case, significant spatial separation between interferer and victim cannot be assumed and coexistence relies upon the following:

- Frequency separation between interferer and victim
- Frequency discrimination of the transmitter and receiver

The worst-case scenarios that can be envisaged, if used to derive the protection criteria, would result in excessive frequency separations between systems operating in adjacent frequency blocks. In effect, excessive guard bands, with the consequential loss of valuable spectrum, would result. This can be avoided through the use of statistical methods to assess the impact of guard bands on a deployment as a whole. The calculations can be repeated many times to build up a reliable picture.

8.1.11.1 BS-to-BS interference

In PMP systems without harmonization, BS-to-BS interference is evaluated by use of a simulation program. It is clear that an interfering BS could be relatively close to a victim BS, but the level of interference depends on the relative locations of the BSs of the two systems, which affects the antenna pointing direction. Analysis shows that a single guard channel between systems will, in general, be a good guideline for uncoordinated deployment when the systems employ similar channel spacings. Where channel spacings are considerably different, one equivalent guard channel may be necessary at the edge of each operator’s block.

8.1.11.2 SS-to-BS interference

In PMP systems, SS-to-BS interference may be evaluated by use of a simulation program. It is clear that an interfering SS could be relatively close to a victim BS, but the level of interference depends on the relative locations of the BSs of the two systems (which affects the antenna pointing direction), on the use of automatic transmit power control (ATPC), and on possible differential rain fading. Analysis of this case, in C.3 and C.13, shows that a single guard channel between systems will in general be a good guideline for uncoordinated deployment. Where channel spacings are considerably different, one equivalent guard channel may be necessary at the edge of each operator’s block.

Where the interferer is a mesh system, the antenna pointing directions are more random and possible multiple interferers have to be considered. An analysis of this situation, in C.12, shows that the same one channel guard band is a good guideline for uncoordinated deployment.

8.1.11.3 SS-to-SS, same area case

This problem may be analyzed by use of Monte Carlo modeling. In general, the probability of interference occurring is low but, when it does occur, the level can be high. Unlike the BS-to-SS case, the high levels of interference are not in predictable parts of the cell(s). Mitigation is by use of guard bands, improved antennas and (in mesh systems) by rerouting so as to avoid the worst pointing directions of antennas. An analysis of this case can be found in C.5 for the PMP case and in C.12 and C.13 for the mesh-PMP case. The case without harmonization is analyzed. The analysis shows that a single guard channel between systems will in general be a good guideline for uncoordinated deployment. Where channel spacings are considerably different, one equivalent guard channel may be necessary at the edge of each operator's block.

9. Mitigation techniques

9.1 General

This subclause describes some of the mitigation techniques that could be employed in case of co-channel interference between systems operating in adjacent areas. As each situation is unique, no single technique can be effective for all cases. In certain circumstances, the application of more than one mitigation technique may be more effective.

In general, analyses to evaluate the potential for interference and any possible mitigation solution should be performed prior to system implementation. Coordination with adjacent operators could significantly lower the potential for interference. Best results may be obtained if full cooperation and common deployment planning is achieved.

9.2 Frequency band plans

By retaining spare frequencies for use only when interference is detected, some potential co-channel and adjacent channel problems can be eliminated.

A similar frequency plan for the uplink and downlink could help to reduce interference for FDD systems. The most problematic interference occurs between base stations, primarily because base stations are typically located on high buildings or other structures and therefore tend to have good clear line of sight (LOS) with neighboring base stations. Base stations typically operate over 360°, and base stations are always transmitting.

Harmonized base stations that transmit in the same subband do not interfere with each other when located in adjacent areas and enable site sharing when located in the same area.

Frequency exclusion provides another, albeit very undesirable, approach for avoiding interference. This involves dividing or segregating the spectrum so that neighboring licensees operate in exclusive frequencies, thus avoiding any possibility for interference. This should be considered an absolute last resort, where all other remedial opportunities have been completely exhausted between the licensed operators.

When tackling coexistence between systems operating in adjacent frequency blocks in the same or overlapping areas, similar equipment channelization schemes at the block edges help to facilitate coexistence between interfering subscriber stations and victim base stations. The effect is to reduce the guard band required between the frequency blocks due to the similarity of the interferer and victim system characteristics. Additionally, similar characteristics could lead to similar cell coverage areas. This may help to minimize the potential for numerous overlapping cells.

9.3 Service area demarcation

If regulators define a service area demarcation boundary in an area of low service demand or in areas that provide natural terrain blockage or separation, then interference across the boundary will tend to be reduced.

9.4 Separation distance/power

One of the most effective mitigation techniques that can be employed is to increase the distance between the interfering transmitter and the victim receiver, thus lowering the interfering effect to an acceptable level. If the distance between the interferer and the victim cannot be increased, then the transmitter power can be lowered to achieve the same effect. However, these options are not always viable due to local terrain, intended coverage, network design, or other factors.

Another possible, but less desirable, option is to increase the transmit power levels of the SSs within a cell or sector in a given service area to improve the signal to interference level into the base station receiver. Operating the SSs “hot” at all times may help to address the adjacent area interference. However, it may introduce other interference scenarios that are equally undesirable, so caution should be exercised if this approach is taken.

When tackling coexistence between systems operating in adjacent frequency blocks in the same or overlapping areas*,* similar operating psd levels help to facilitate coexistence between interfering base stations and victim subscriber stations.

9.5 Co-siting of base stations

Careful planning is required for co-sited antennas. When tackling coexistence between FDD systems operating in adjacent frequency blocks in the same or overlapping areas with defined uplink and downlink frequency bands, co-siting of base station transmitters help to facilitate coexistence

9.6 Coexistence with PTP systems

In order to facilitate coexistence between PMP systems and PTP systems operating in adjacent frequency blocks in the same area, a minimum separation and angular decoupling is needed between the PTP site and any base station site. To provide the maximum decoupling, the best possible PTP antenna RPE performance is preferable.

9.7 Antennas

9.7.1 Antenna-to-antenna isolation

In practice, sector antennas that are directed to the same sector may be co-located. Careful planning is required in this case. Such co-location involves two primary configurations, depending on whether the antennas are mounted on the same mounting structure Antenna-to-antenna isolation is dependent on factors like site location, mounting configurations, and other system level issues. Even with seemingly uncontrollable factors, there is a need for isolation between the antennas directed to the same sector. For guidance, the antenna-to-antenna isolation for antennas pointed to the same sector with sector sizes of 90^o and less should be 60 dB to 100 dB.

9.7.2 Orientation

In certain system deployments, sectorized antenna are used. A slight change in antenna orientation by the interfering transmitter or victim receiver can help to minimize interference. This technique is especially effective in the case of interference arising from main-beam coupling. However, as with separation distance, although to a lesser degree, this mitigation technique may not be practical in certain deployment scenarios.

9.7.3 Tilting

Like changing the main-beam orientation, the downtilt of either the transmitting antenna or receiving antenna can also minimize the interfering effect. A small change in downtilt could significantly change the coverage of a transmitter, thereby reducing interference to the victim receiver. However, in some systems the downtilt range could be quite limited due to technical or economic reasons. This could render this technique impractical.

9.7.4 Directivity

In problematic areas near the service area boundaries where interference is of concern, consideration can be given to using high-performance antenna with high directivity as opposed to a broader range sectorized antenna or omni-directional antenna.

Another possible option is to place the base station at the edge of the service area or boundary and deploy sectors facing away from the adjacent licensed area. Interference is then avoided through the front to back lobe isolation of the base station antennas. This can exceed 30 dB, to accommodate QPSK and 16-QAM modulation.

9.7.5 Antenna heights

In circumstances where adjacent licensed base stations are relatively close to each other, another possible technique to avoid interference is to place the base station antenna at lower heights to indirectly create LOS blockages to neighboring base stations. This solution will be impractical in many cases, as it will significantly reduce coverage area. However, under certain conditions, it may be the best option available for addressing the interference issue.

9.7.6 Future schemes

In the future, alternative schemes may be available. For example, such as adaptive arrays or beam-steering antennas can focus a narrow beam towards individual users throughout the service area in real-time to avoid or minimize coupling with interfering signals. Beam shaping arrays, which create a null in the main beam towards the interfering source, represent another possible approach towards addressing interference.

9.7.7 Polarization

Cross polarization can be effective in mitigating interference between adjacent systems. A typical cross-polarization isolation of 25–30 dB can be achieved with most antennas today. This is sufficient to counter co-channel interference for QPSK and 16-QAM modulation schemes. As with other mitigation techniques, cross polarization is most effective when coordination is carried out prior to implementation of networks to accommodate all possible affected systems.

9.8 Blockage

Natural shielding, such as high ground terrain between boundaries, should be used to mitigate interference where possible. When natural shielding is not available, the use of artificial shielding, such as screens, can be considered.

9.9 Signal processing

Using more robust modulation and enhanced signal processing techniques may help in deployment scenarios where the potential for interference is high.

9.10 Receiver sensitivity degradation tolerance

Receiver sensitivity determines the minimum detectable signal and is a key factor in any link design. However, as the level of receiver noise floor increases, the sensitivity degrades. This, in turn, causes reduction in cell coverage, degradation in link availability, and loss of revenues. The factors contributing to the increase in noise power divide into two groups: internal and external. The internal factors include, but are not limited to, the noise generated by various components within the receiver, intermodulation noise, and intra-network co-channel and adjacent-channel interference. The external factor is internetwork interference. The amount of degradation in receiver sensitivity is directly proportional to the total noise power added to the thermal noise, ΣI, consisting of intranetwork and internetwork components.

$$\sum \mathrm{I} = P_{\text{intra}} + P_{\text{inter}} \tag{2}$$

In order to reduce the inter-network contribution to ΣI, it is recommended that the effect of any fixed BWA network on any other coexisting BWA network should not degrade the receiver sensitivity of that fixed BWA network by more than 1 dB. This is the level that triggers the coordination process described in 7.1.

9.11 Subscriber Tx lock to prevent transmissions when no received signal present

In the absence of a correctly received downlink signal, the SS transmitter should be disabled. This is intended to prevent unwanted transmission from creating interference that would prevent normal system operation due to antenna misalignment. The SS should continuously monitor the received downlink signal and, if a loss of received signal is detected, no further transmissions should be allowed until the received signal is restored. If the received signal is lost while the unit is transmitting, the unit is permitted to complete the current transmission. This gives the SS a mechanism to notify the base station of the system fault.

9.11.1 Fail-safe

It is recommended that the subscriber and base station equipment have the ability to detect and react to failures, either software or hardware, in a manner to prevent unwanted emissions and interference. The following is an example list of items the equipment should monitor:

- Tx phase-locked loop lock status
- Power Amplifier drain voltage/current
- Main power supply
- Microprocessor watchdog

The implementation of monitoring, preventative, and/or corrective actions is considered vendor-specific. The intent is to prevent transmissions that may result in system interference due to individual SS failures.

Annex A

(informative)

Test and measurement/hardware parameter summary

The text in A.1 and A.2 is based on the test and measurement procedures recommended in Canadian standards RSS-191 [B11].

A.1 Testing of unwanted emissions

Some transmitters may be frequency agile to cover several authorized bands and may deploy a band edge RF filter only at the extremities. The option for spectrum segregation implies that operator segregation edge frequencies may also occur within an authorized band. Thus unwanted emissions at authorized band edges or at segregation band edges well inside the agility range of the transceiver may not benefit from the band edge RF filter and may be more severe (or “worst-case”) compared to emissions at the extreme upper or lower edges.

To facilitate assessing emissions at a generic mid-band segregation or authorized band edge, a virtual block edge is defined and testing (the results are assumed to be valid across the complete operational band) should be implemented at this virtual block edge. Unwanted emissions should be measured at the output of the final amplifier stage or referenced to that point. In addition to active amplifiers, the final amplifier *stage* may contain filters, isolators, diplexers, ortho-mode transducer, etc. as needed to meet emission requirements.

A.1.1 Methodology

Single-carrier and multicarrier requirements are described below. If multicarrier operations are intended, then both requirements should be met. “Multicarrier” refers to multiple independent signals (QAM, QPSK, etc.) and does not refer to techniques such as OFDM.

Single-carrier and multicarrier tests should be carried out relative to a virtual block edge (defined in Table A.1). The virtual block edge is located within the assigned band (see Figure A.1). When a transmitter is designed to only operate in part of a band (e.g. because of frequency division duplexing), the virtual block edge should be inside the designed band of operation. The occupied bandwidth of the carrier(s) should be closer to the center of the block than the virtual block edge. The virtual block edge is only to be used for testing and does not impact an actual implementation in any way. One virtual block edge (at frequency f_{vl}) should be inside the lower edge of the designed or assigned band and the other virtual block edge (at frequency f_{vu}) should be inside the upper edge of the designed or assigned band.

Table A.1—Minimum separation between actual and virtual band edge for different bands

Band	Minimum separation between actual and virtual block edge
24/26 GHz	10 MHz
28 GHz	40 MHz
38 GHz	10 MHz

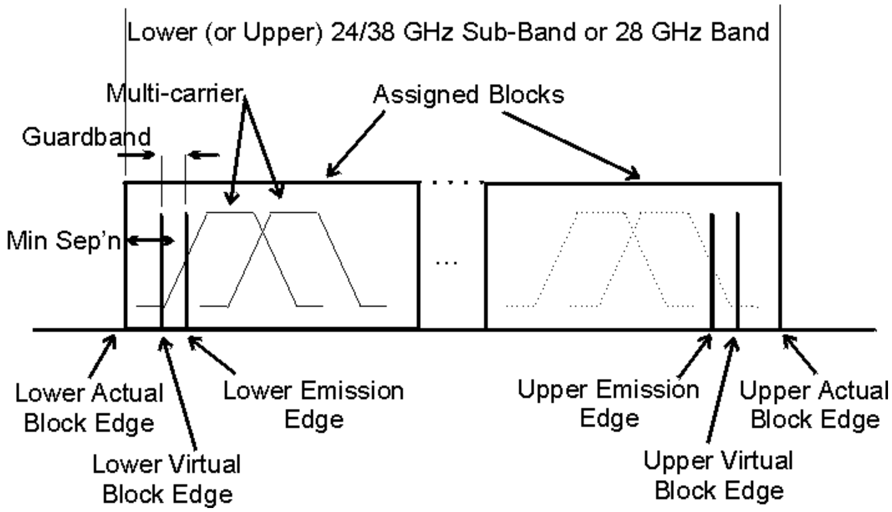

Figure A.1—Band edge definitions

Unwanted emissions should be measured when the transmitter is operating at the manufacturer's rated power and modulated with signals representative of those encountered in a real system operation. Unwanted emissions should be measured at the output of the final amplifier stage or referenced to that point. The measurement can be done at the transmitter's antenna connector as long as there is no frequency combiner in the equipment under test. It is important however that the point of measurement for this test be the same as the one used for the output power test. The point of measurement and the *occupied* bandwidth (B_0) should be stated in the test report. Single-carrier and multicarrier requirements are described below. If multicarrier operations are intended, then both requirements should be met. "Multicarrier" refers to multiple independent signals (QAM, QPSK, etc.) and does not refer to techniques such as OFDM.

The purpose of specifying the tests relative to the virtual block edges is to avoid the attenuating effects of any RF filters that may be included in the transmitter design, so that the spectrum mask limits of 6.1.3 are applicable to any channel block.

Note that although testing is specified relative to the virtual block edges, the transmitter is expected to perform similarly for all frequencies within the designed band. Therefore, to reduce the number of test runs, the Lower Virtual Block Edge can be in one assigned band and the upper virtual block edge can be in another assigned band.

The search for unwanted emissions should be from the lowest frequency internally generated or used in the device (local oscillator, intermediate or carrier frequency), or from 30 MHz, whichever is the lowest frequency, to the fifth harmonic of the highest frequency generated or used, without exceeding 40 GHz.

A.1.2 Single-carrier test

For testing nearest the lower virtual block edge, set the carrier frequency f_L closest to the lower virtual block edge, taking into account any guardband used in the design of the equipment, record the carrier frequency f_L, the virtual block edge frequency f_{VL}, the guardband (f_{LG}) and plot the RF spectrum. Likewise, perform the highest frequency test with the carrier frequency, f_U nearest the upper virtual block edge. Record the carrier frequency, the virtual block edge frequency (f_{VU}), the guardband (f_{UG}) and the RF spectrum plot. The guardband is the frequency separation between the virtual block edge and the edge (99%) of the occupied emission.

The user manual should contain instructions, such as details on the minimum guardband sizes required to ensure that the radios remain compliant to the certification process.

It is to be noted that the regulations may permit licensees to have more than one frequency block for their systems. Equipment intended to have an occupied bandwidth wider than one frequency block per carrier should be tested using such a wideband test signal for the 6.1.3 requirement.

A.1.3 Multi-carrier test

This test is applicable for multicarrier modulation (not OFDM). It applies equally to multitransmitters into a common power amplifier. Note that the multicarrier transmitter should be subjected to the single-carrier testing, described above, in addition to the tests specified below.

For multi-carrier testing, the single-carrier test method of A.1.2 is to be used except that the single carrier is replaced by a multicarrier modulated signal that is representative of an actual transmitter. The number of carriers should be representative of the maximum number expected from the transmitter, and be grouped side by side nearest the lower virtual block edge, with lower guardband, f_{LG}, if required by the design of the equipment. Likewise test nearest the upper virtual block edge. Record their spectrum plots, the number of carriers used and the guardband sizes (f_{LG}, f_{UG}), the carrier frequencies and the virtual block edge frequencies.

Notwithstanding the requirements in Table A.1, any equipment which uses the complete block or multiple blocks for a single licensee can include the attenuating effect of any RF filters in the transmitter design within the multicarrier test, in which case the virtual and actual block edge frequencies will be the same.

The user manual should contain instructions, such as details on the minimum guardband sizes required and the maximum number of carriers or multi-transmitters permitted, to ensure that the radios remain compliant to the testing process.

A.2 Measuring frequency stability

As discussed in 6.1.2, the RF carrier frequency should not depart from the reference frequency (reference frequency is the frequency at 20 C and rated supply voltage) in excess of +10 parts per million. The RF frequency of the transmitter should be measured as follows:

a) At temperatures over which the system is designed to operate and at the manufacturer's rated supply voltage. The frequency stability can be tested to a lesser temperature range provided that the transmitter is automatically inhibited from operating outside the lesser temperature range. If automatic inhibition of operation is not provided the manufacturer's lesser temperature range intended for the equipment is allowed provided that it is specified in the user manual.

b) At 85% and at 115% of rated supply voltage, with temperature at +20 C.

In lieu of meeting the above stability value, the test report may show that the frequency stability is sufficient to ensure that the occupied bandwidth emission mask stays within the licensee's frequency band, when tested to the temperature and supply voltage variations specified above. The emission tests should be performed using the outermost assignable frequencies that should be stated in the test report.

A.3 European conformance test standards

ETSI has published a standard, in a number of parts, that deals in detail with the conformance testing procedures for Fixed Wireless Access equipment. EN 301 126-2-1 to EN 301 126-2-1-5, titled “Fixed Radio Systems; Conformance testing” has the following subparts:

- Part 2-1: Point-to-Multipoint equipment; definitions and general requirements
- Part 2-2: Point-to-Multipoint equipment; Test procedures for FDMA systems
- Part 2-3: Point-to-Multipoint equipment; Test procedures for TDMA systems
- Part 2-4: Point-to-Multipoint equipment; Test procedures for FH-CDMA systems
- Part 2-5: Point-to-Multipoint equipment; Test procedures for DS-CDMA systems

Additionally drafting activity on a Part 2-6, catering for Multicarrier TDMA equipment, is complete. Copies of the published standards are available for download from the ETSI Web Site.

Annex B

(informative)

Power spectral flux density (psfd) calculations

Assuming a typical receiver noise figure of 6 dB, then the thermal noise power spectral density of the receiver is calculated as follows:

$$N_o = 10\log(kT_o) + N_F \tag{B.1}$$

$$N_o = -144 + 6 = -138 \text{ dBW/MHz}$$

where

No = Receiver thermal noise power spectral density (dBW/MHz)
kT_0 = Equipartition Law (–144 dBW/MHz)
N_F = Receiver noise figure (6 dB)

At 6 dB below N_o, the interference power level (I_{tol}) into the receiver is –144 dBW/MHz (–138 – 6).

The spectral power flux density (psfd) at the antenna aperture is calculated as follows:

$$psfd = \frac{P_r}{A_e} = \frac{P_r}{\lambda^2 \frac{G}{4\pi}} = Pr - 10\log(\lambda^2) - G + 10\log(4\pi) \tag{B.2}$$

where

P_r = interference power level into receiver (–144 dBW/MHz);
A_e = effective antenna aperture;
λ = wavelength; and
G = antenna gain.

B.1 20–30 GHz

Assuming an operating frequency of 28 GHz (λ = 0.011 m) and a typical base station antenna gain of 20 dBi, then the tolerable interference level is given as follows:

$$\begin{aligned} P_{\text{sfdBS}} &= -144 - 10\text{Log}(0.011^2) - 20 + 10\ \text{Log}(4\pi) = -144 + 39 - 20 + 11 \\ &= -114\ (\text{dBW/m}^2)/\text{MHz} \end{aligned}$$

Note that the base station receiver is considered only in this analysis (not the subscriber station). This is primarily due to the fact that BSs are typically located on high buildings/structures with omni-directional coverage which tend to increase their probability of achieving line of sight (LOS) to adjacent licensed area transmitters. SSs, on the other hand, tend to be situated at lower altitudes which reduces the probability of LOS (due to obstacles/clutter) to adjacent area systems. Furthermore, SSs have highly directional antennas (narrow beamwidths) which further reduces the probability that they will align with an interference source from an adjacent area.

A sample calculation is given below to determine the feasibility of meeting the psfd limit between a BS transmitter and BS victim receiver. The formula for psfd is as follows:

$$psfd_{\mathrm{victim}} = P_{\mathrm{TX}} + G_{\mathrm{TX}} - 10\log(4\pi) - 10\log(R) - A_{\mathrm{losses}} \tag{B.3}$$

where

P_{Tx} = transmitter power (–25 dBW/MHz)
G_{Tx} = transmitter antenna gain in the direction of the victim receiver (18 dBi)
R = range (60 000 m)
A_{losses} = atmospheric losses, ~0.1 dB/km

The values given in brackets represent typical fixed BWA parameters.

Using the radio horizon range of 60 km from above, the psfd at the victim base station receiver antenna is:

$$psfd_{\mathrm{victim}} = -25 + 18 - 10\log(4\pi) - 20\log(60\,000) - 60*0.1 = -120\ (\mathrm{dBW/m^2})/\mathrm{MHz}$$

The –120 (dBW/m^2)/MHz value is lower than the –114 (dBW/m^2)/MHz tolerable level, therefore, the 60 km range is considered reasonable as a first level trigger point. Note that the above psfd calculation assumes free space propagation and clear line of sight, i.e., complete first Fresnel zone clearance.

B.2 38–43.5 GHz

Equation (B.2) shows a dependency of the psfd on the wavelength lambda (λ). Thus the psfd limit of –114 (dBW/m^2)/MHz needs correction to the 38–43.5 GHz band. At 40 GHz, λ = 0.075 m and substituting into Equation (B.2) (retaining other assumptions) gives –111 (dBW/m^2)/MHz.

Annex C

(informative)

Description of calculations and simulation methods

For the simulations described in C.1 to C.3, typical fixed BWA 26 GHz transmission parameters, as identified in 6.1.1, were employed. For ITU rain region K, these result in a maximum cell radius of R = 3.6 km and a corresponding rain fade margin of 25 dB. A clear sky cell edge ATPC of 15–20 dB was employed for the TS[8]-to-BS interference analysis. As subsequently identified, unwanted emissions were specified to be –20 dBc at a first adjacent carrier flanking and –49 dBc at a second adjacent carrier flanking. These values correspond to a numerical integration of the power within the adjacent channel bandwidth based on the ETSI Type B emissions mask specified in [B4]. For simulations that take the impact of correlated/uncorrelated rain fading into consideration, the diameter of a rain cell was specified to be 2.4 km. This is in accordance with the rain cell model described in ITU-R recommendation P.452-2 [B20]. This model assumes a rain cell to be circular with a uniform rain rate within its diameter. Using this model, the relative rain loss of both a victim and an interference transmission vector can be estimated. The simulations described in C.4 to C.8 employed comparable transmission criteria to that described above, with the exception that the emissions coupling from a second adjacent carrier was –54 dBc.

Both ETSI point-to-multipoint antenna RPE masks [B5], [B6] and the RPE masks defined in 6.2 were employed in the simulations.

C.1 Subscriber to hub (TS to CS), adjacent area, same frequency

These simulations examine interference sensitivity across a service area or business trading area boundary. They examine the interference sensitivity between co-channel interference situations assuming an uncoordinated alignment of interference and victim sectors. Interference impairment is appropriately expressed in terms of power spectral flux density (psfd) defined in terms of (dBW/m^2)/MHz.

The simulation estimates consider only a clear sky environment, as this is the trigger threshold on which operator coordination is recommended. The recommended boundary psfd trigger level for operator coordination is –114 (dBW/m^2)/MHz.

C.1.1 Simulation model (TS to CS)

Figure C.1 illustrates the simulation model. Two co-channel sectors are exposed to each other across a boundary.

As is typical with cellular system engineering analysis, TS locations are located on the periphery of the sectors. The distance between the CS locations is D and the distance from an interference TS to the victim CS is R_i. Randomly selected angle locations are set for the interference TS interference positions and each establish some angle φ relative to their boresight position and the victim CS. This establishes the TS antenna angular discrimination to be expected from a specific interference link.

As the operator assignments for sector location are assumed to be uncoordinated, the victim link CS boresight angle is set at some value α and the interference CS boresight is set at some value β. Angle α establishes the RPE antenna discrimination to be expected from the victim CS link.

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[8] Since some of the annexes come from outside sources, different terminology from that used in the main text may be found. Terminal station (TS) is equivalent to subscriber station (SS), central station (CS) and hub are both equivalent to base station (BS).

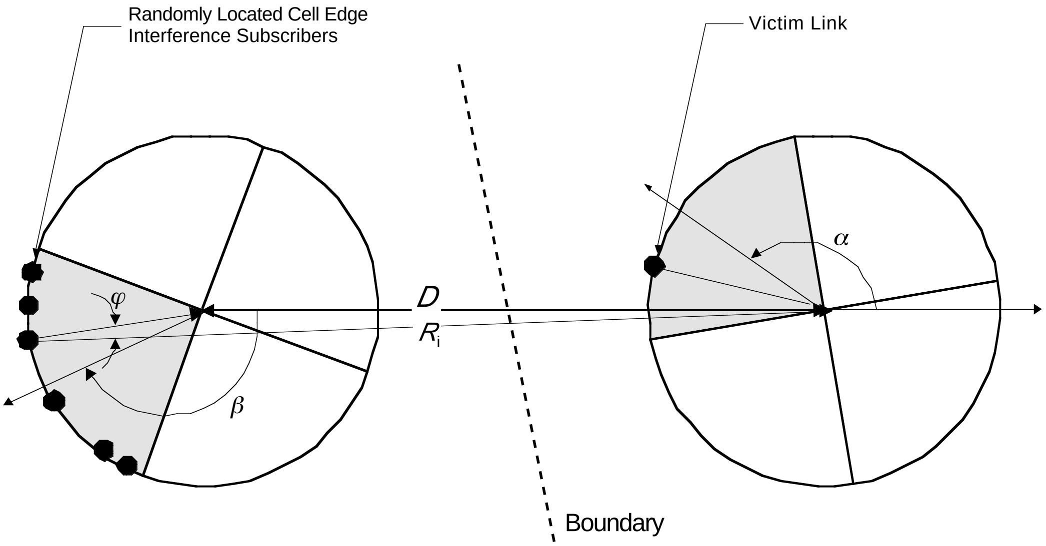


Figure C.1—Simulation Model for TS to CS

To complete a simulation, both CS boresight angles are independently incremented in 5° spin intervals. For each spin, the worst *C/I* estimate is computed from the 20 interference locations and entered into a database. For each CS spin, the locations of the interference TS positions are modified by changing the random number seed. A simulation, parameterized against *D*, thus consists of 5184 interference level estimates. These values are sorted to provide a cumulative distribution function (CDF) estimate of psfd versus *D*.

C.1.2 Simulation results

The main conclusions from this analysis are as follows.

Typically, the simulation results indicate that at CS separation distances of less than 40 km, 7–10% of deployments will require coordination. Beyond 40 km, there were no exposures that exceeded the –114 (dBW/m^2)/MHz psfd trigger threshold. These simulations assumed an LOS coupling mechanism of the interference signal vectors. When a distance proportional random blockage algorithm (80% at 60 km) was added to the simulations, the psfd coordination requirement reduced to 2–4% of the interference exposures at less than a CS separation distance of 40 km. These prior conclusions are of course conditioned on the transmission parameters employed in the simulations. Increased transmit EIRP would have a direct effect on the coordination distance requirements.

The simulation results indicate that, in general, interference coordination requirements have a low sensitivity to antenna sidelobe RPE beyond the main lobe. One exception was found to be the ETSI CS1 antenna. ETSI CS1 antennas (sectored hub antennas) show much more rapid increase of psfd values above the threshold than other types. These antennas should therefore be used with care and antennas with better sidelobe performance are generally preferred.

While antennas with excellent sidelobe suppression were not identified as an absolute requirement for this coexistence scenario, they may be a requirement for control of an operator's intrasystem interference control. However, the specification of these requirements is outside the scope of this document.

C.2 Hub to subscriber (CS to TS), same area, adjacent frequency

These simulations address the case of multiple operators deployed in a given geographical area that are employing adjacent frequencies. In this case, the most serious conflicts occur when two operators have adjacent carriers of the same polarization. Dependent on an operator’s ability to establish reserve carrier assignments there may or may not be a guard band(s). Hence, the NFD protection ratio may be either 20 dB (adjacent channel operation) or 49 dB (one guard channel). The simulations assume that both operators employ the same carrier bandwidth (assumed as 28 MHz for the analysis). Also assumed is that both operators employ a comparable set of transmission parameters.

C.2.1 Simulation model (CS to TS)

Figure C.2 illustrates the simulation model. The interference CS is placed in the victim sector at some parameterized distance S between the hub centers.

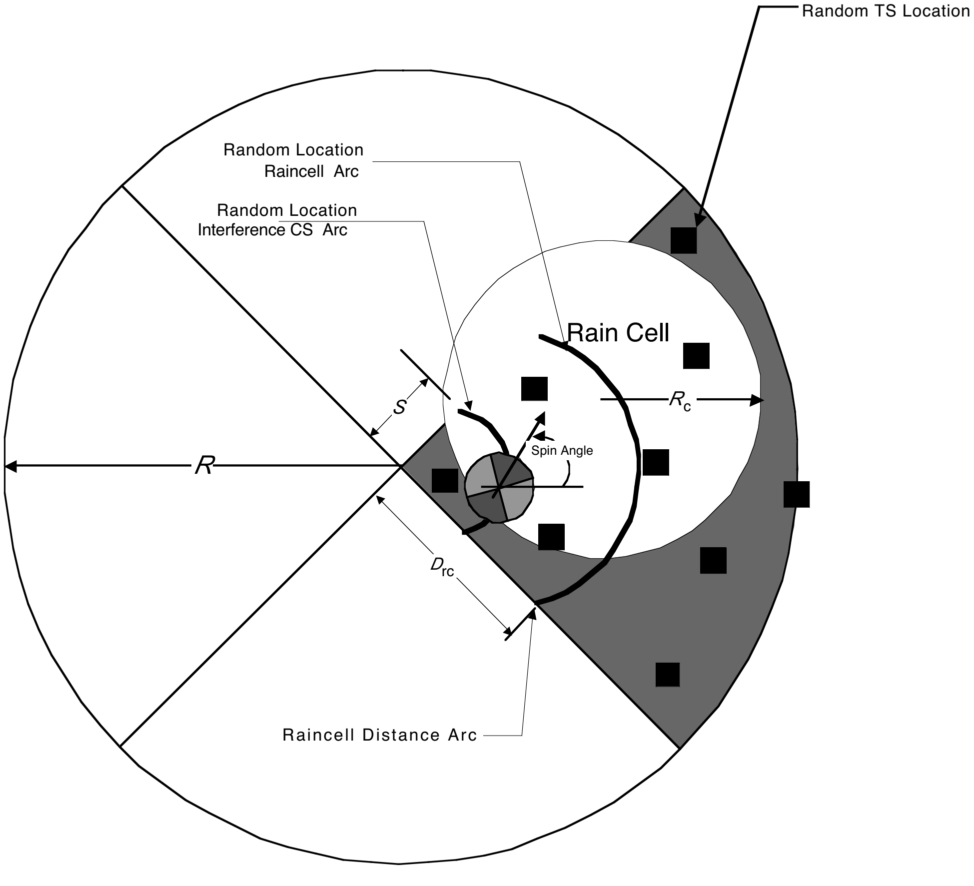


Figure C.2—Simulation model for CS-TS

Relative angular position of the interference CS is set random for each rotational spin of sector alignments. As the interference CS is always deemed to be within the victim sector, only the sector alignment of the interference CS needs to be varied. Spin increments were taken at 5°.

A rain cell of radius R_c = 1.2 km is positioned in the sector at some parameterized distance D_{rc}. To ensure that at least one victim link experiences the full rain attenuation loss, D_{rc} is restricted to be within the range of 1.2 km to 2.4 km. A worst-case value for D_{rc} would tend to be 1.2 km. At this distance, the rain cell just touches the victim sector, thus maximizing the number of TS locations that experience significant rain loss.

For each rotational spin of the interference CS, the angular position of the rain cell is randomized. Angular rotation is restricted to be within +/–45°, thus ensuring that the full diameter of the rain cell is always within the victim sector.

Twenty victim subscribers are selected for each rotational spin. For each spin, the rain loss of interference and victim vectors is computed, based on the transmission geometry that establishes the distance within the rain cell that the interference vector experiences rain attenuation. Victim signal levels are computed based on the transmission parameters, link distance, and rain loss. Interference signal levels are similarly computed but with the inclusion of antenna angular discrimination, relative frequency polarization, and NFD. A single interference computation accounts for the contribution of each of the four CS sectors and each spin represents 20 independent *C/I* estimates. Thus, a simulation is represented by 1440 *C/I* estimates. These are sorted and employed to develop a CDF for *C/I* at given values for *S* and D_{rc}.

C.2.2 Simulation results

The simulation results for a first adjacent flanking (zero guard band) were unsatisfactory. Under clear sky conditions, the *C/I* impairment was found to be distance dependant and ranged from 2% to 10% at a *C/I* = 19 dB. At a *C/I* = 25 dB, the impairment range extended from 3% to 30%. The impairment was identified to be distance dependent, with the worst cases occurring at small CS–CS separation distances. The minimum separation distance examined was 0.3 km while the maximum was 2 km. Under rain fading conditions, the simulation results became significantly more severe. Here, the simulations identified that in excess of 20% of the exposures would experience a *C/I* < 19 dB and that in excess of 30% of the exposures would experience a *C/I* < 25 dB. Worst-case interference estimates were found to occur at CS separation distances of the order of 0.6R. This is consistent with the simulation conclusions described in C.4.

As expected, the inclusion of a one-carrier bandwidth guard band demonstrates a significant improvement in terms of the probability of *C/I* impairment. Under rain faded conditions, worst case *C/I* < 19 dB exposures are less than 2% and for a *C/I* < 25 dB are less than 4%. As with the simulation results described in C.1 above, the *C/I* performance was found to be relatively insensitive to antenna RPE outside the main lobe.”

C.3 Subscriber-to-hub (TS-to-CS), same area/adjacent frequency

These simulations also address the case of multiple operators deployed in the same geographical area that employ adjacent carrier frequencies. However, in this case there are now two sets of TS carriers that need to be considered and both uplink groups apply adaptive transmit power control (ATPC), dependent on the relative values of link distance and rain attenuation. In the CS-to-TS analysis, both victim and interference CS transmitters operate without power control. Consequently, transmit EIRP was balanced. However in this case there could be a significant EIRP differential, dependant on distance and rain loss differential.

The simulation analysis assumes that both operators employ equal bandwidth transmissions. Both operators’ transmissions are assumed to be co-polarized. The NFD selected for a simulation is in accordance with the carrier separation specified for the simulation.

C.3.1 Simulation model (TS-to-CS)

The layout model is as shown in Figure C.3 where it may be noted that the two sets of subscriber stations likely experience different magnitudes of rain attenuation. Consequently, their ATPC and EIRP will differ as a function of their distance from their serving TS and the adjustment for rain attenuation. It is now convenient to consider the victim CS to be as illustrated in Figure C.4. The rain loss of each of the 20 interference TS links is computed based on their exposure distance within the rain cell. The Tx power of each interference TS is then ATPC adjusted to ensure that its combined distance and rain loss signal level suppression is such that it meets margin objectives. The signal level of each interference path into the victim CS is then computed based on the transmission criteria of the link.

To simplify the complexity of the analysis, it is assumed that victim TS locations are also area proportionally located. Hence, 50% of the victim subscribers are at a distance > than 0.75R from the victim CS. An average victim rain loss is then computed by sampling the intersection of the victim hub with the rain cell across 5^o increments. Victim link rain loss is then set at this average and victim link transmission distance is referenced to 0.75R. Victim link ATPC is then set accordingly.

This methodology ensures a 50% TS estimate accuracy for victim link rain loss. However, if the rain loss never exceeds the margin requirement, then all victim link received signals are at the margin requirement. This is the case for many simulation configurations and is guaranteed for clear sky conditions. In such cases, all victim TS signal vectors arrive at the victim CS at the margin Rx signal level.

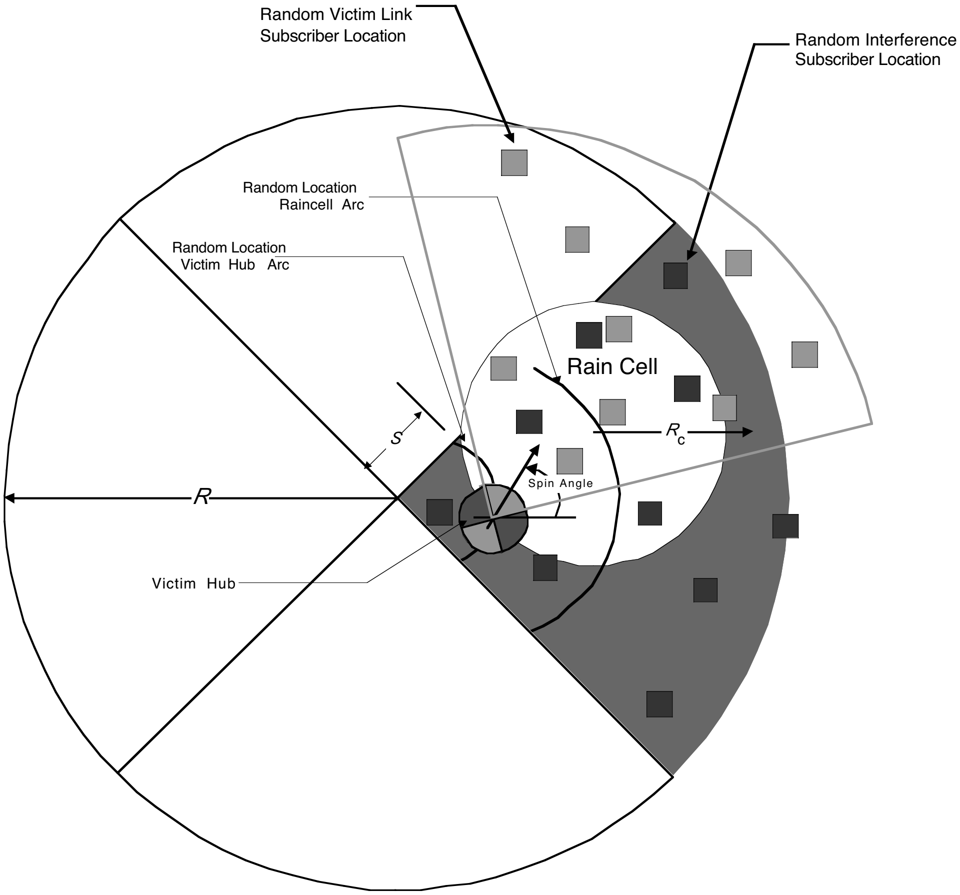


Figure C.3—Layout Model

C.3.2 Simulation results

As with the CS-to-TS case discussed above, interference levels were found to be unsatisfactory in the absence of a guard band. *C/I* impairment probability was found to be comparable to the results identified in C.2 for both clear sky and rain faded system scenarios. Similar to the preceding discussions, antenna RPE characteristics outside the main lobe did not introduce a significant change in performance estimation results. All of the preceding excludes consideration of the ETSI CS1 antenna mask as it was not considered subsequent to simulation results described in C.1.

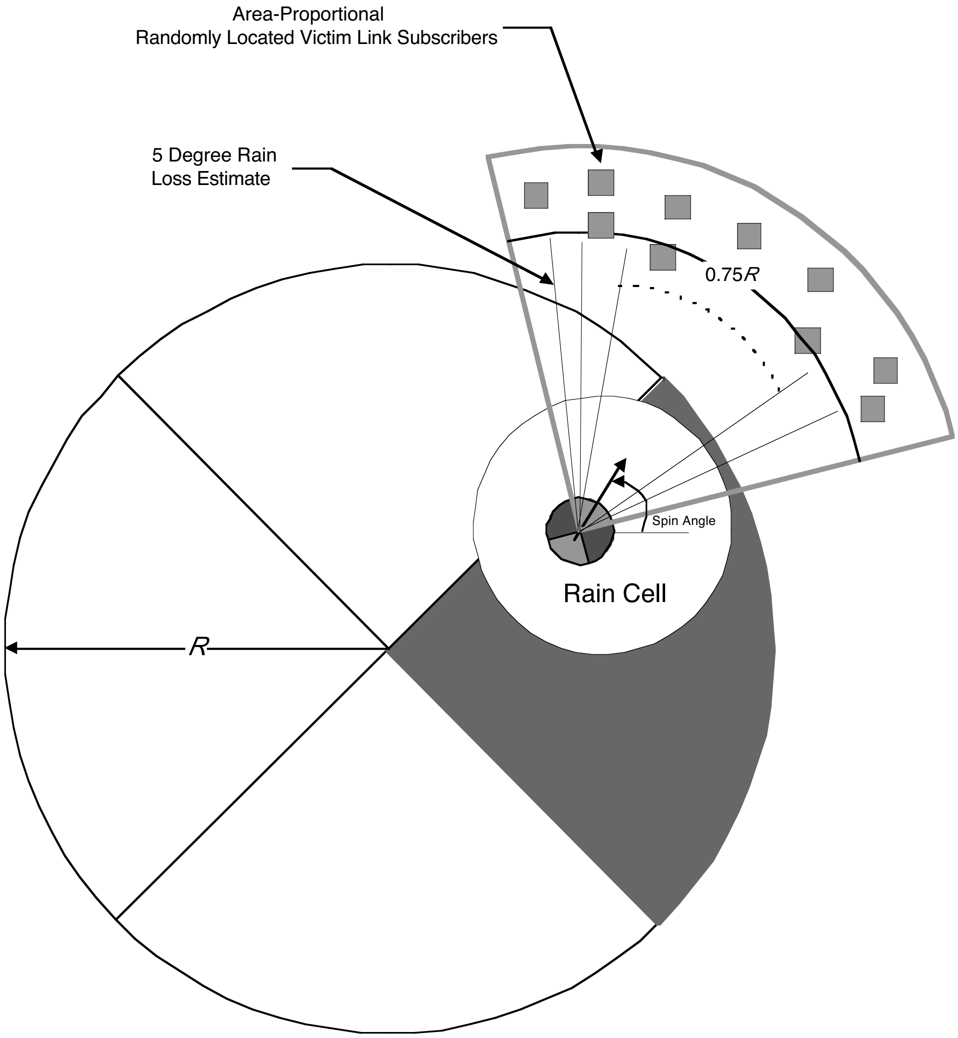


Figure C.4—Victim CS

C.4 Hub to subscriber (CS to TS), same area, adjacent channel, interference area method

This simulation derives the interference area (IA) for systems operating in the same area. It applies to FDD and TDD systems. The IA is the proportion of the sector area where interference is above the target threshold, equivalent to the probability that a TS placed at random will experience interference above the threshold. Analysis shows that the worst case is where the interfering CS is spaced approximately 0.6 times the cell diagonal away from the serving CS and when a rain cell in the most adverse position reduces the wanted signal. This is illustrated in Figure C.5.

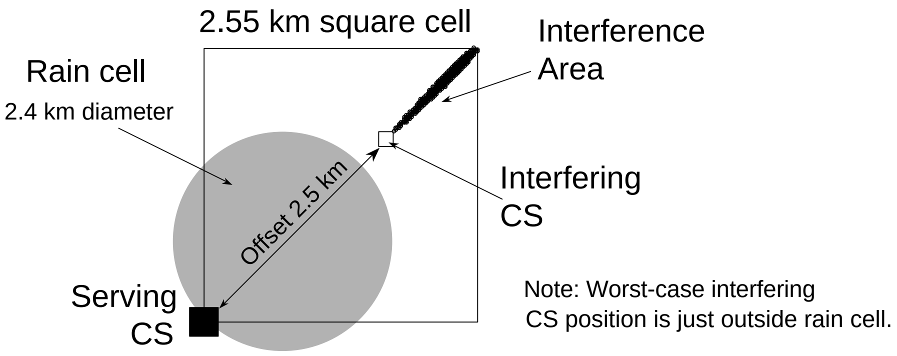


Figure C.5—Worst-Case Interference

C.4.1 Simulation method

A large number of random TS positions are generated within the cell area. For each position, the wanted and unwanted carrier levels are computed, based on angles, distances, antenna patterns and gains and the appropriate NFD. The TS positions where the *C/I* is below the required target are counted and plotted. The simulation has been repeated using different antenna patterns to determine the importance (or otherwise) of using highly specified antennas.

C.4.2 Simulation results

For a single channel guard band, in all cases the IA is relatively small and its location is predictable. Typically, it occurs in the "shadow" of the interfering CS and is a narrow area following the cell diagonal and ending at or inside the cell boundary. The exact shape depends on the choice of TS antenna (smaller with a better antenna). For the parameters chosen, the IA was in the range 0.5% to 2%. Within the IA, the interference level can vary from a level that degrades performance to one that is unworkable. In the absence of rain fading, the IA is significantly reduced.

C.5 Subscriber-to-subscriber (TS-to-TS), same area, adjacent channel, TDD only

This simulation computes the *C/I* ratio at a victim TS, the interference arising from another TS in a cell, which overlaps the coverage of the wanted cell. The interfering and victim antennas are directional. Wanted and interfering cells may partly or wholly overlap. The geometry is shown in Figure C.6.

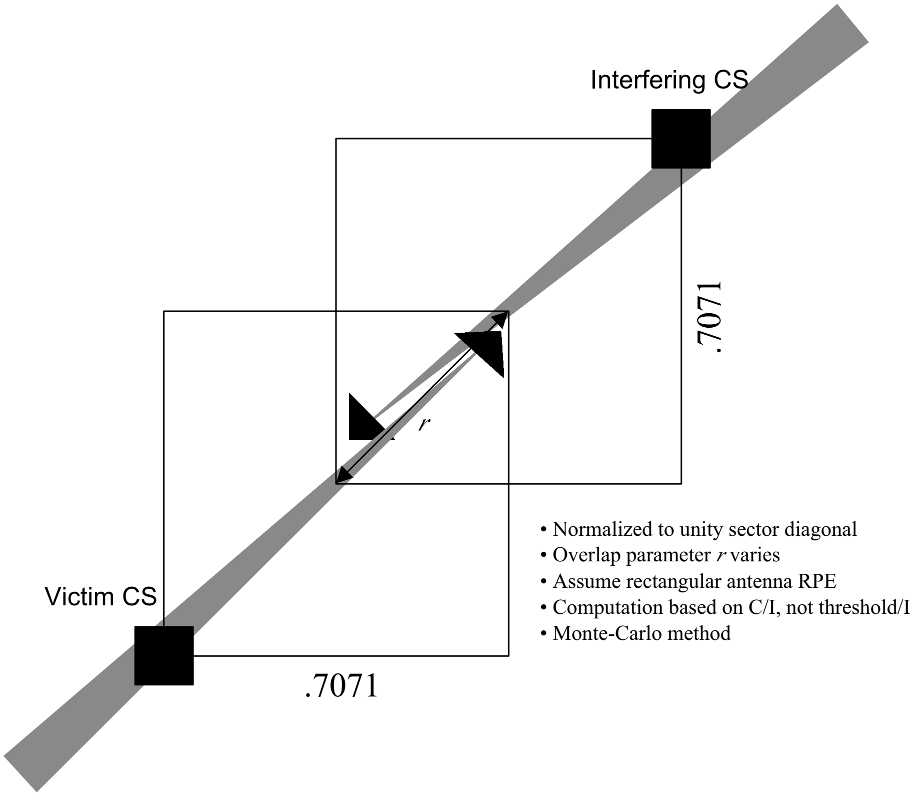


Figure C.6—Subscriber-to-subscriber (TS-to-TS), same area, adjacent channel, TDD only

C.5.1 Simulation method

The overlap parameter *r* is set at a value between zero (cell sectors just touching) and 2.5. At a value of 2, the victim and interfering CS locations are the same. The simulation places a number of terminals randomly inside each cell. The program then computes whether or not there is mutual visibility between all pairs of terminals. Mutual visibility is decided on the basis of a simple “rectangular” antenna RPE. Where there is mutual visibility, the *C/I* ratio at the victim station is computed, allowing for uplink power control. The results are added to the statistics and the simulation repeated a large number of times. Different values of *r* are used to determine the probability of conflict (mutual interference) for various values of overlap of the cells. The cumulative probability distribution of *C/I* values is then plotted for different values of *r*.

C.5.2 Simulation results

The *C/I* ratio probability distribution curves, adjusted for system factors including the NFD for one guard channel between systems, show the following results:

- For small overlap values, the C/I ratio can be low, but the probability is also very low.
- The maximum probability of conflict occurs at an overlap value of $r = 2$, where the probability rises to approaching 10%. However, the C/I ratio is then at an acceptable level.
- Rain fading has a neutral or beneficial effect. Subscriber to subscriber (TS to TS), co–channel, adjacent area (TDD).

C.6 Subscriber to subscriber (TS to TS), co-channel, adjacent area (TDD)

This simulation computes the *C/I* ratio at a victim TS, the interference arising from another TS in a cell in an adjacent area. The interfering and victim antennas are directional. Wanted and interfering cells may partly or wholly overlap. The geometry is similar to that shown in Figure C.6 for the TS to TS same area case, but with larger values of cell offset.

C.6.1 Simulation method

The same Monte Carlo method is used as for the TS-to-TS same area case, with larger cell offset values and with no NFD (i.e., the victim is co–channel to the interferer). Atmospheric attenuation is ignored in the calculations.

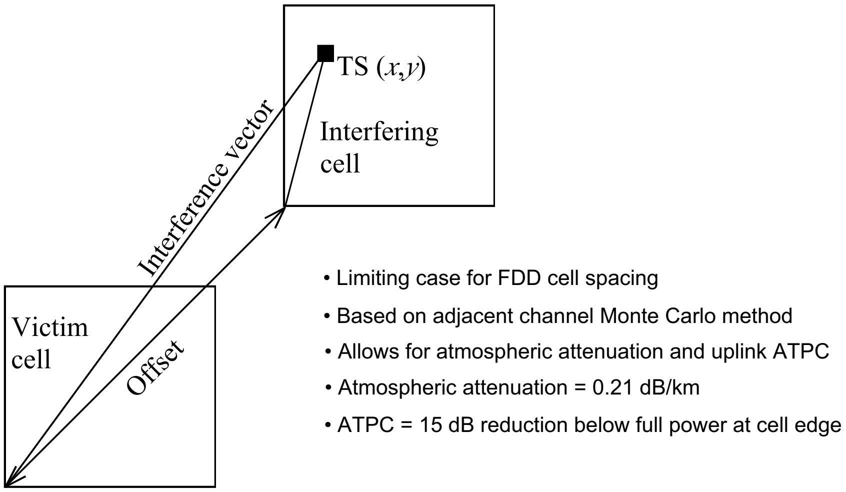
C.6.2 Simulation results

The *C/I* probability curves show that at overlap values of as little as $r = 5$, the *C/I* values reach acceptable levels and the probability of the highest values is still very low. This corresponds to a distance, which is lower than that required to reduce CS–CS or CS–TS interference to an acceptable level.

It is concluded that TS-to-TS interference is not the limiting case for adjacent area co-channel operation.

C.7 Subscriber-to-hub (TS–to-CS), co- channel, adjacent area

This simulation applies both to the FDD and TDD case. It is based on the same Monte Carlo method as that used for the adjacent channel simulations. The path geometry is shown in Figure C.7.



- Limiting case for FDD cell spacing
- Based on adjacent channel Monte Carlo method
- Allows for atmospheric attenuation and uplink ATPC
- Atmospheric attenuation = 0.21 dB/km
- ATPC = 15 dB reduction below full power at cell edge

Figure C.7—Path geometry for TS-to-CS co-channel simulation (FDD and TDD)

C.7.1 Simulation method

The IA is constructed in a similar way to the hub to sub same area case. In this case, it is the interfering TS that lies in the IA, the victim being the distant BS. Atmospheric attenuation and uplink ATPC are taken into account. Additionally, the effect of using different TS antennas is calculated. The TS antenna patterns considered were drawn from the standard EN 301 215-2 [B6] and from the work of ETSI WP-TM4 detailed in Annex D. Charts are also constructed of the probability of interference against the cell offset value.

C.7.2 Simulation results

With the parameters chosen, the interference probability and the interference area fall to negligible values when the offset (distance between hubs of the victim and interfering cells) reaches approximately 35 km. This “worst case” result does not depend on the antenna RPE.

At lower values of offset, the IA can be rather large. It drops sharply as the “worst case limit is approached.

It is concluded that for TS-to-CS co-channel operation an offset of approximately 35 km is a good guideline for uncoordinated deployment.

C.8 Hub-to-hub (CS-to-CS), co-channel, multiple interferers

This simulation considers the case of multiple CS interferers in a multi-cell deployment, interfering with a victim CS (or other station) in a neighboring LMDS system deployment (Figure C.8). The victim station is assumed to be on a high site, so that path obstruction due to intervening terrain is unlikely to occur. This is a low probability situation, but where it occurs, it is important to note the likely value of interference that could be received.

The original simulations also studied the case of multiple TS interferers.

The calculations determine the psfd at the boundary of the victim system deployment and so can be applied to any type of victim station that has a wide enough antenna beam pattern to encompass all the interferers.

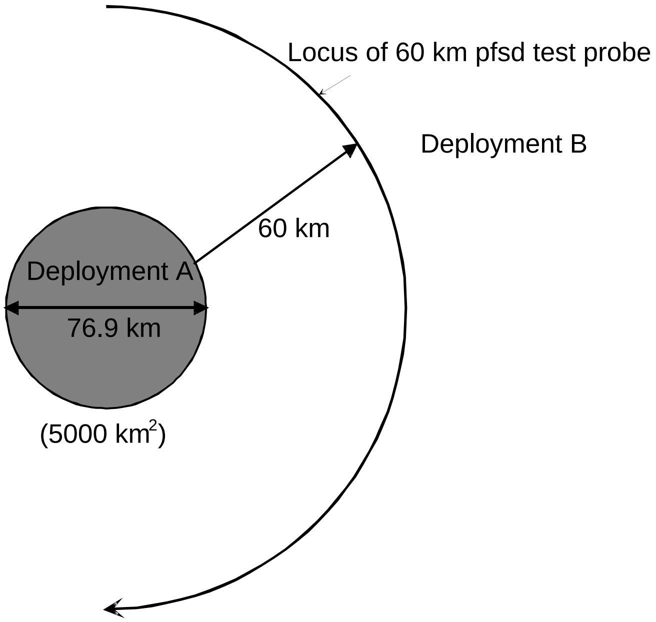


Figure C.8—Simulation Geometry

C.8.1 Simulation method

The interfering system deployment (A) contains a number of BS sites that may be co-channel to the victim station in (B). Calculation shows that up to 70 BS sites could be involved. The victim station is 60 km from the boundary of the deployment (A) and on a high site 500 m above local ground level. Earth curvature is taken into account, but no additional building or ground obstruction is considered.

The simulation places the 70 interfering stations randomly over the area of (A) and pointing in random directions. Realistic antenna RPEs and transmitter EIRPs are used. The sum of the power from all interferers that are not over the horizon is taken into account in calculating the psfd along the 60 km locus and the results plotted as cumulative probability distributions.

C.8.2 Simulation results

The multiple BSs produce unacceptable psfd levels at 60 km, when there is no additional path loss due to buildings or terrain. With typical system parameters, the nominal psfd value of –114 (dBW/m^2)/MHz (derived in Annex B of this document) is exceeded by 7–12 dB.

Thus, in the case where terrain is unfavorable, additional measures may be needed to reduce the interference to acceptable levels. This situation is likely to be atypical and in most circumstances buildings, trees and terrain will reduce the interference considerably.

C.9 Mesh to PMP CS, co-channel, adjacent area

This simulation models a high-density mesh network interfering with a PMP CS sector (hub sector) placed in the most severe position and pointed directly at the mesh. In a mesh network, there are potentially multiple interferers on each channel, so that the signal from all possible contributing stations adds together at the victim station. The geometry is shown in Figure C.9.

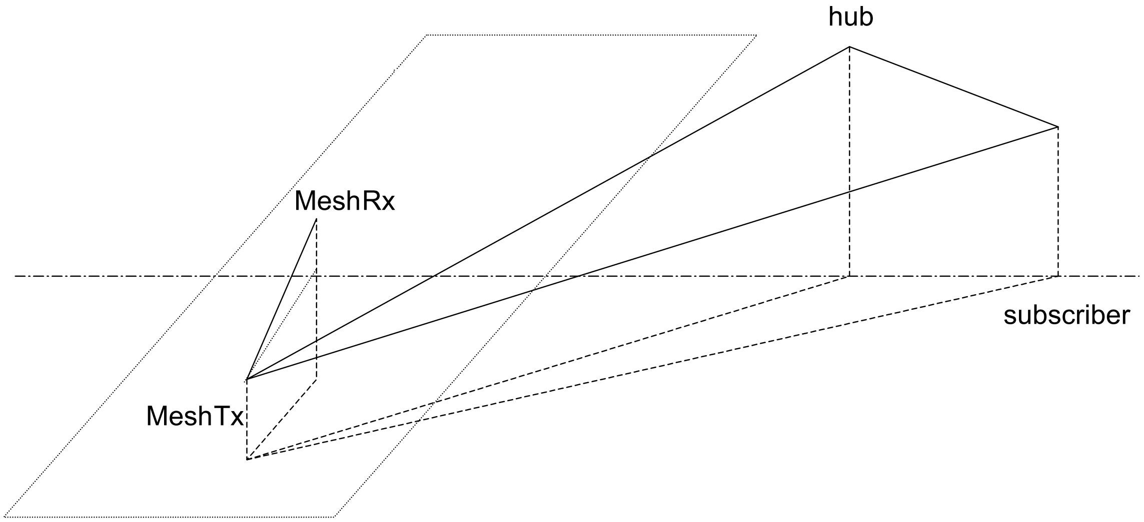


Figure C.9—Mesh to PMP CS, co-channel, adjacent area

C.9.1 Simulation method

The main attributes of the model are as follows:

- Monte Carlo simulation with realistic MP-MP system parameters.
- Line-of-sight propagation probabilities calculated from Rayleigh roof height distribution function [B24].
- Interfering power summed at PMP base or subscriber using full 3-D geometry to compute distances and angles between lines of sight and antenna bore-sights.
- Effect of automatic power control granularity (ATPC) included.
- PMP RPEs for 24-28 GHz band to EN 301 215-2 V1.1.1 [B6] with BS elevation profile ignored for realistic worst case.
- MP-MP antenna RPE model for 24–28 GHz band simulates an illuminated aperture with side-lobes to EN 301 215 V1.1.1.
- Atmospheric attenuation to ITU-R P.676-3 [B21]. Cloud and fog to ITU-R P.840-2 23. Rain attenuation to ITU-R P.838 [B22].
- Dry, storm, and frontal weather patterns considered.

The interference target maximum level in the model is –144 dBW/MHz measured at the victim receiver input. A large number of trial runs of the simulator tool (typically 10 000) are used to generate a histogram of interfering signal against probability of occurrence. The deduced minimum spacing is based on the worst-case value of interference. In practice this has a very low probability so that the results indicated below are conservative.

C.9.2 Simulation results

The results show that the required spacing between the mesh edge and the nearest hub location depends on antenna heights of the hub and the mesh stations, but is not significantly affected by antenna RPE. For typical system parameters, quite modest geographical spacing is possible. For example, a hub 50 m above ground level will require a geographical spacing of only 12 km from the mesh edge (service area boundary of the mesh, assuming it is populated right up to the boundary). Most trial configurations gave much better results (lower interference) so that by careful deployment, lower spacing is practical.

Rain fading was found to have negligible effect on the results, either for the case of the storm cell or a general rain front (rain to one side of a line and dry on the other).

The guideline for PMP to PMP network separation 35 km will be conservative for a mesh deployment. A reduced spacing will be possible without coordination and a further reduction will be possible by coordinating with neighboring operators.

C.10 Mesh to PMP TS, co-channel, adjacent area

This simulation is similar to that for the mesh to PMP CS case. It models a high-density mesh network interfering with a PMP TS associated with a nearby CS sector (hub sector). The TS is pointed towards its serving CS (hub). As with the CS case, there are potentially multiple interferers on each channel, so that the signal from all possible contributing stations adds together at the victim station. The geometry is the same as that shown in Figure C.9.

C.10.1 Simulation method

The method is identical to that for the CS case, except that the antenna RPE for the PMP TS is different (TS antenna RPE from EN 301 215-2 V1.1.1 [B6]) and the TS always points towards its own hub (CS). The height of the TS antenna is varied to test sensitivity. Many trial runs (typically 10 000 for each set of parameters) are executed to produce a histogram as in the CS case.

C.10.2 Simulation results

For all practical hub (CS) locations, TS heights, and locations in the PMP cell, it was found that interference levels were lower than those received by the corresponding hub (CS). Thus, the controlling factor is the mesh to hub spacing. At the 12 km spacing determined for mesh to 50 m high hub, all TS interference is below the target level of –144 dBW/ MHz, for any randomly selected mesh configuration.

Antenna RPE within the mesh was found to be noncritical.

Rain fading (storm cell or rain front) had negligible effect on the results.

C.11 Mesh to PMP CS, same area, adjacent frequency

This simulation uses a slightly modified model to that for the adjacent area case. The same full 3-D geometry is used in computations, except that the victim hub or TS is now inside the area occupied by the high-density mesh network. Again, there are potentially multiple interferers on each channel, so that the signal from all possible contributing stations adds together at the victim station.

C.11.1 Simulation method

Again a Monte Carlo simulation method is used, in which a large number of trial runs are computed using realistic system parameters and varying the locations of the radio stations for each run. The results are presented in statistical form. The same CS antenna pattern is used as for the adjacent area case. The orientation of the antenna in this case is not so important as it lies inside the mesh network. Full 3-D geometry is taken into account. The results are computed with various values of NFD appropriate to adjacent channel operation and for frequency spacings of one or more guard channels. Dry conditions, storm cells, and rain fronts are considered in the calculations.

C.11.2 Simulation results

The results are available in chart form, showing the probability that the total interference exceeds a given value. The target value for relatively interference-free operation is again taken as –144 dBW/MHz measured at the victim receiver input.

For adjacent channel operation (no guard channel), the probability of exceeding the target interference level is around 35%. This is too high for uncoordinated operation, although it indicates that with careful deployment adjacent channel operation may sometimes be possible.

With one guard between the systems, the probability of exceeding the threshold falls to a negligible level (less than 0.02%). Thus, it can be concluded that, in respect of CS interference, a single guard channel is a suitable guideline for planning deployment of systems, without coordination.

C.12 Mesh to PMP TS, same area, adjacent frequency

This case is very similar to the same area CS case. The system geometry is nearly identical, except for the typical antenna heights used for the PMP TS. The same full 3-D geometry is used in computations, except that the victim hub or TS is now inside the area occupied by the high-density mesh network. Again, there are potentially multiple interferers on each channel, so that the signal from all possible contributing stations adds together at the victim station.

C.12.1 Simulation method

Again a Monte Carlo simulation method is used, in which a large number of trial runs are computed using realistic system parameters and varying the locations of the radio stations for each run. The results are presented in statistical form. The same TS antenna pattern is used as for the adjacent area case. The orientation of the antenna in this case is not so important as it lies inside the mesh network. Full 3-D geometry is taken into account. The results are computed with various values of NFD appropriate to adjacent channel operation and for frequency spacing of one or more guard channels. Dry conditions, storm cells and rain fronts are considered in the calculations.

C.12.2 Simulation results

The results are available in chart form, showing the probability that the total interference exceeds a given value. The target value for relatively interference-free operation is again taken as –144 dBW/MHz measured at the victim receiver input.

For adjacent channel operation (no guard channel), the probability of exceeding the target interference level is around 12%. As with the CS case, this is too high for uncoordinated operation, although it indicates that with careful deployment adjacent channel operation may sometimes be possible.

With one guard between the systems, the probability of exceeding the threshold falls to a very low level (less than 0.35%). Thus, it can be concluded that, in respect of TS interference, a single guard channel is a suitable guideline for planning deployment of systems, without coordination.

The interference mechanism is also very similar to that for the TS-to-TS case of PMP networks, so that a result showing that a single guard channel is a satisfactory planning guideline is not unexpected.

C.13 General scenario, same area, adjacent frequency

This simulation tests a general case of PMP and mesh systems in the same area, in adjacent frequency bands. It analyzes the cases of PMP CS to PMP CS, PMP TS to PMP TS, high-density mesh to PMP CS and high-density mesh to another mesh.

Results from worst-case calculations for example systems operating in the adjacent frequency/same area scenario show that under certain conditions a NFD of 97 dB could be required to ensure interference-free operation in an adjacent channel. In practice this is unrealizable. Therefore a small risk of interference needs to be tolerated along with some frequency separation. In order to assess the level of risk of interference with certain assumed frequency separations, Monte Carlo style analyses were carried out. Operator deployments were considered with systems that employed identical channelization schemes and system deployments with different channelization schemes.

C.13.1 Simulation method

A Monte Carlo style analysis was carried out whereby the interfering stations were randomly distributed around the victim station for numerous trials. An exclusion distance between the victim and interferer of 50 m was chosen (in order to avoid possibility of co-siting the two). The victim is pointing in the same direction throughout the simulation in order to randomize the directivity between victim and potential interferers.

Interference was calculated for each trial and interference probability density function and cumulative distribution function (CDF) generated.

PMP Base stations are assumed to be transmitting at full power throughout the modeling. ATPC is deployed for both PMP and mesh subscribers to counteract rain fading and different distances. In the first set of trials, it is assumed that the interferer and victim operate with the same channel spacing. In the second set of trials, it was assumed that the interferer channelization is four times the victim channelization scheme. In the case where equal channelization is employed, a guard band of half the channel spacing is assumed at the edge of each operator's frequency band. In the case of unequal channelization schemes, the interferer channelization was four times the victim channelization. In this scenario, the following two cases were investigated:

- A guard band at the edge of each operator's block equal to half their respective channelization scheme
- A guard band at the edge of each operator's block equal to one channel of their respective channelization scheme

In assessing the off-frequency interference levels, the transmitter emission masks of Figure C.10 were assumed, based upon EN301-213 [B4] (112 MHz systems) although modified for ultimate attenuation.

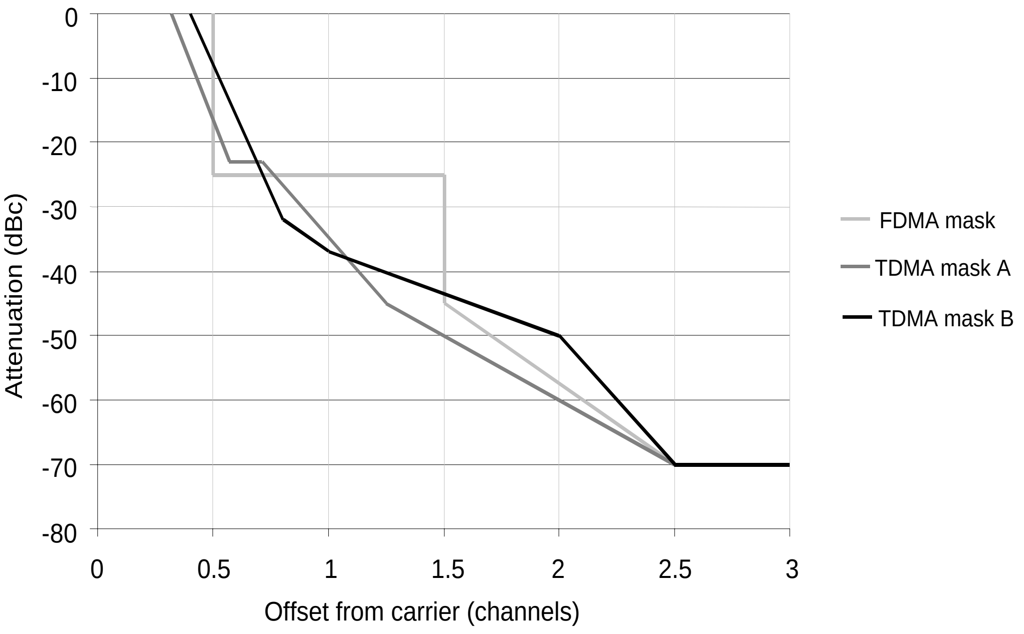


Figure C.10—Transmitter masks based on EN 301 213 spectrum masks and –70 dBc floor

The interference limit of –146 dBW/MHz is consistent with an *I/N* = –10 dB based on the parameters in Annex E.

Two interferer densities were assumed of 0.01 per km^2 for PMP networks and 0.45 per km^2 for high-density (HD) mesh networks. It can be seen that only in the case of a high-density mesh network interfering with another mesh network subscriber station is the interference limit exceeded in more than 1% of trials.

C.13.2 Simulation results

Table C.1 summarizes the simulation results.

Table C.1—Simulation Results

Channel spacing in each adjacent block	**Guard frequency width**	**Interference path and station type**	**Interference level exceeded for 1% of trials or less** (dBW/MHz)	**Interference limit**
Identical	1 channel spacing equivalent	PMP Base to PMP Base	–171	–146 dBW/MHz
		PMP Sub to PMP Sub	–164	
		HD Mesh to PMP Base	–157	
		HD Mesh to Mesh	–144	
Nonidentical (Ratio 4:1)	Sum of half of each nonidentical channel spacing	PMP Base to PMP Base	–147	
		PMP Sub to PMP Sub	–142	
		HD Mesh to PMP Base	–132	
		HD Mesh to Mesh	–120	
Nonidentical (Ratio 4:1)	Sum of each nonidentical channel spacing	PMP Base to PMP Base	–167	
		PMP Sub to PMP Sub	–167	
		HD Mesh to PMP Base	–156	
		HD Mesh to Mesh	–146	

It is concluded that where networks are operating with identical channel spacings, a guard band per operator of one half the channel spacing is likely to be sufficient for reliable coexistence in the same geographic area.

To ensure substantially interference-free coexistence between two networks where there is a significant difference in the channel spacings deployed, a guard band equal to a single channel spacing will need to be accommodated within each operator’s band.

Annex D

(informative)

Work of other bodies

D.1 ETSI WP-TM4

ETSI Working Party TM4 is developing a technical report for publication titled “Rules for Coexistence of PTP and PMP systems using different access methods in the same frequency band” [B8]. This report covers the coexistence of Point-to-Multi-point FWA systems with other FWA systems and with Point-to-Point systems deployed in the same frequency band and in the same (or near) geographical area. It examines the interference scenarios and methodologies for evaluating interference, identifies critical parameters required for standards, and looks at mitigation methods.

Certain key assumptions are made regarding the deployment of PMP systems, reflecting the expectation that a number of operators with frequency block assignments deploying a range of equipment utilizing different multiple access methods and duplexing methods are possible. It is recognized that as a result of facilitating coexistence between the operators, some deployment constraints may result.

D.1.1 Interference classes

Based upon typical fixed service frequency plans a set of interference classes are identified. These are summarized in Table D.1.

Table D.1—Interference classes

PMP to PMP coexistence		**PMP to PTP coexistence**	
Class A1	CS interferer into victim TS (down/down adjacency)	Class B1	CS interferer into victim PP receiver (PMP Down/PP Rx adjacency)
Class A2	TS interferer into victim CS (up/up adjacency)	Class B2	PP interferer into victim CS (PP Tx/PMP Up adjacency)
Class A3	CS interferer into victim CS (down/up adjacency)	Class B3	TS interferer into victim PP receiver (P-MP Up/PP Rx adjacency)
Class A4	TS interferer into TS victim (up/down adjacency)	Class B4	PP interferer into victim TS (PP Tx/PMP Down adjacency)

Having identified the interference classes with typical frequency plans in mind, the range of interference scenarios are examined against a number of system possibilities to determine which interference classes are appropriate for further study. For example in the case of two PMP TDD systems deployed by adjacent operators all classes A1 to A4 above can be seen to be possible to a greater or lesser extent. For PMP FDD systems, specific cases only of classes A1 to A4 are appropriate. For example, if subbands are defined within the frequency band plan for uplink and downlink transmission directions then only classes A1 and A2 are appropriate. In the case of PMP and PTP deployment, classes B1 to B4 above all apply to some extent.

D.1.2 Deployment scenario assumptions

In order to evaluate the degree of coexistence between PMP systems, the following assumptions are made:

- One cell from each of the two systems is considered, with a generic distance between hubs.
- The whole cell area is covered with the frequency channel adjacent to the frequency block (channel) assigned to another operator.
- All radio paths are in perfect LOS.

D.1.3 Methodology

Using these assumptions all the potential interference scenarios are evaluated, disregarding the potential mitigation due to sector antenna, the usage of other frequency/polarization channels and cell pattern deployment. Expressions for the potential interference are developed using the concept of net filter discrimination (NFD) in order to estimate the amount of interference (coming from the interfering channel) falling within the receiver filter of the useful system.

These expressions can then be used for each class of interference to assess the following "measures of coexistence:"

- Class A1: the percentage of cell area (%KO) where the interference generated from the interferer CS towards the victim TS produces a *C/I* smaller than a given C/I threshold.
- Class A2: the percentage of cell area (%KO) where the interference generated from an interferer TS towards the useful CS produces a *C/I* smaller than a given threshold.
- Class A3: the minimum distance between the two CS's (interferer and victim) in order to achieve the *C/I* threshold.
- Class A4: the percentage of cell area (%KO) where the interference generated by an interferer TS towards the victim TSs produces a *C/I* smaller than a given threshold.

The methodology and the interference parameters summarized above enable evaluation of the coexistence (interference) problems from both the analytical perspective (one simple equation) and the numerical point of view (complete evaluation of *C/I* over the cell area, using a software tool).

D.1.4 Resultant considerations

In carrying out this evaluation a number of considerations have come to light associated with the interference classes identified above. These are summarized as follows:

a) Class A1 and A2:
    1) Site sharing improves coexistence possibilities.
    2) Site sharing helps to reduce the guard band requirements (possibly zero).
    3) Near site sharing helps also.
    4) With no site sharing, at least one channel equivalent guard band required between adjacent operator assignments.
    5) Similar EIRPs at the central station reduces interference.

b) Class A3:
    1) Site sharing is not possible, therefore minimum separation required.
    2) Separation distance can be minimized with a guard band.
c) Class A4:
    1) Exacerbated by a large number of terminal stations.
    2) Guard band is required.

Additionally it is noted that use of ATPC, equal channelization schemes, and similar receiver performance reduces the guard band requirements. Defined uplink and downlink frequency subband planning reduces the number of interference scenarios for FDD PMP systems.

d) Classes B1 and B2:
    1) Site sharing is not possible, therefore minimum distance and angular decoupling is required.
    2) Distance and angular separation can be minimized with a guard band.
e) Classes B3 and B4:
    1) Site sharing is not possible.
    2) Geometrical decoupling is impossible to achieve due to the spread of TS over the PMP deployment area.
    3) High frequency separation is required, usually more than one channel equivalent guard band.

D.1.5 Worked examples

Finally, the report provides a number of worked examples for PMP systems in lower frequency bands and in the 26 GHz band. These examples include FDD systems employing TDMA and FDMA methods and the lower frequency example examines the impact of utilizing “standard” performance characteristics versus “actual” or typical characteristics. The results show a range of possibilities ranging from zero guard band for near identical systems with good cooperation between operators to the need for two equivalent channel guard bands where nonidentical systems are deployed and poor cooperation exists between operators.

D.2 Industry Canada (IC)

Industry Canada, in consultation with manufacturers and service providers, has conducted studies dealing with coordination between fixed broadband wireless access operators. Technical standards including maximum allowable EIRP, out-of block emission limits and coordination process have been established. Moreover, a US/Canadian bilateral arrangement is already in place for the 24/38 GHz band to facilitate frequency sharing along the border.

The documents ([B10], [B11], [B12], [B13], and [B14]) dealing with the above technical standards, referred to as Standards Radio System Plan (SRSP), Radio Standards Specification (RSS) for the 24 GHz, 28 GHz, and 38 GHz, and US/Canadian Bilateral Arrangement for the 24/38 GHz bands, can be found at http://strategis.ic.gc.ca/spectrum.

D.3 Radio Advisory Board of Canada (RABC)

The Radio Advisory Board of Canada (RABC) has also conducted technical studies dealing with operator-to-operator coordination issues. A paper was issued as an input to the Industry Canada regulation.

This paper entitled “RABC Pub. 99-2: RABC Study Leading to a Coordination Process for Systems in the 24, 28 and 38 GHz Bands” [B25] recommends a coordination process using distance as first trigger and two psfd levels that trigger different actions by the operators.[9]

If the boundary of two service areas is within 60 km of each other, then the coordination process is invoked. Two psfd levels are proposed for coordination. The first one, Level A, represents a minimal interference scenario where either licensed operator does not require coordination. A second, Level B, typically 20 dB higher than A, represents a trigger for two possible categories: if the interference is above A but below B, then coordination is required with existing systems only. If the interference is greater than Level B, then coordination is required for both existing and planned systems. Table D.2 below summarizes psfd Levels A and B for the three frequency bands.

Table D.2—Proposed psfd levels in the 24, 28 and 38 GHz bands

Frequency band (GHz)	psfd Level A [(dBW/m^2)/MHz]	psfd Level B [(dBW/m^2 /MHz]
24	–114	–94
28	–114	–94
38	–125	–105

The much lower psfd levels at 38 GHz are to ensure protection to point-to-point systems allowed in this band in Canada. The coordination procedure is graphically summarized in Figure D.1.

The paper can be found at http://www.rabc.otawa.on.ca/english/pubs.cfm and shows how the values were derived.

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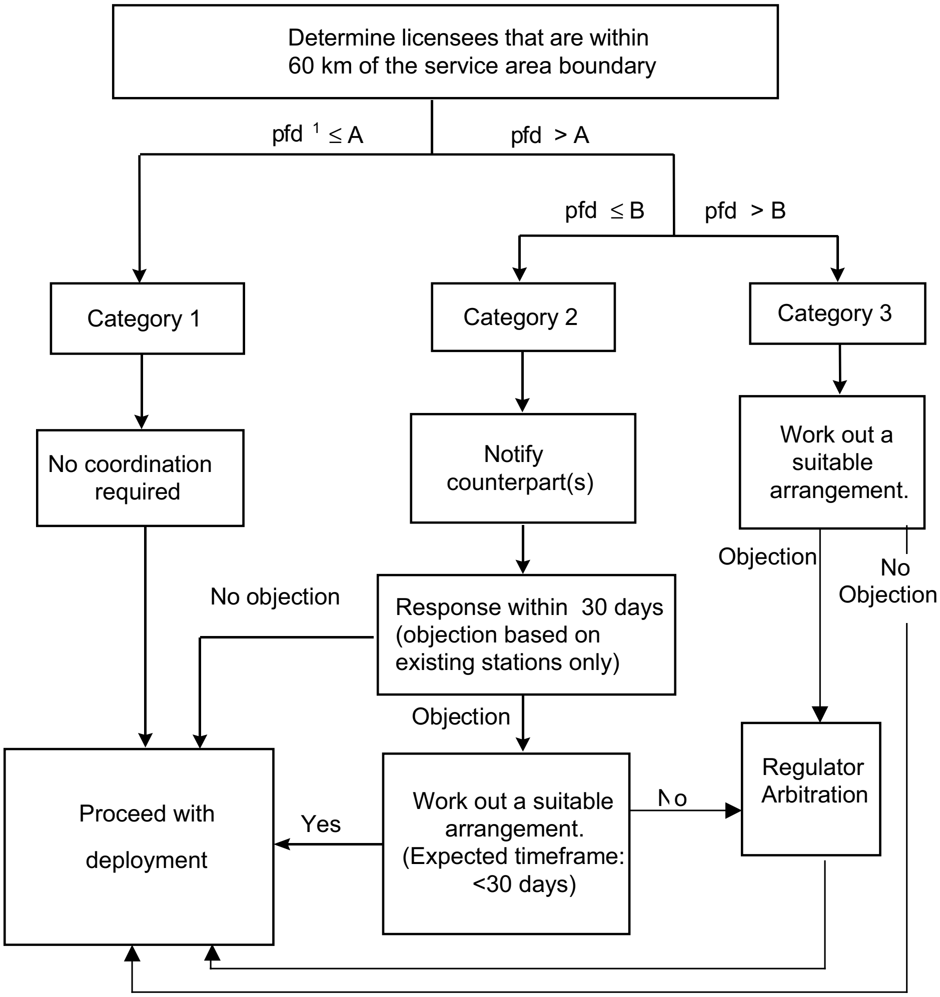
[9] Courtesy Radio Advisory Board of Canada



[1] The pfd is calculated at the service area boundary of the respective counterpart(s).

Figure D.1—Coordination process recommended in RABC paper

D.4 Radiocommunications Agency (UK-RA)

The UK-RA has commissioned technical studies dealing with BFWA interoperator coexistence at 28 and 42 GHz. A report titled “BFWA coexistence at 28 and 42 GHz” and a companion extended study are publicly available from the RA web site under the Business Unit/Research–Extra-Mural R&D project section http://www.radio.gov.uk/busunit/research/extramen.htm. The work studied the issues from the point of view of a regulator wishing to put into place coexistence guidelines for BFWA operators to be licensed in the UK. It addresses both interference scenarios and provides recommendations for psfd trigger levels and guard frequencies based upon tolerable *I/N* of –10 dB and –6 dB.

D.5 CEPT/ERC

The European CEPT has carried out work within its Spectrum Engineering Working Group concerning the coexistence of FWA cells in the 26/28 GHz bands. The completed report, ERC Report 099 [B2], is available from the European Radiocommunication Office at http://www.ero.dk. The report considers both interference scenarios and concludes with recommendations regarding guard frequencies and separation distances. The concepts of interference scenario occurrence probability (ISOP) and interfered area (IA) feature extensively in the analyses documented.

Annex E

(informative)

UK Radiocommunications Agency coordination process

E.1 Introduction

An approach has been proposed to derive guidelines in the UK for BFWA interoperator coordination between licensed areas that abut. It reduces the area in which an operator needs to take some coordination action, allowing him to deploy in an unconstrained manner in greater parts of his or her licensed area than suggested by the recommendations in this Recommended Practice (see 4.2.1 through 4.2.11). This approach increases the risk of unacceptable interference near the boundary and shares the burden of coordination between the operators across the licensed area boundary. Additionally the deploying operator needs only consider the interference impact of certain stations on a station-by-station basis.

This is achieved by defining a boundary psfd trigger level applied on a single interferer basis in conjunction with a coordination zone along the licensed area boundaries, shared equally between the operators. The single interferer trigger limit has been tested in a Monte Carlo style simulation in order to test its adequacy and assess the likelihood of harmful interference into a neighboring licensed area.

E.2 Coordination triggers

In effect, the coordination distance, which is based on EIRP and an interference threshold at the victim of $I/N = -10$ dB, forms the first trigger for coordination action followed, if required, by calculation of boundary psfd. If the boundary psfd exceeds the threshold then some further action is required to either re-engineer the interfering station or to enter into a negotiation with the neighboring operator.

The baseline coordination distance from the licensed area boundary is effectively half the minimum separation distance derived from a worst-case minimum coupling loss (MCL) calculation between typical interferer and victim systems detailed below.

The boundary psfd trigger is based upon the acceptable I/N at the typical victim receiver, but reflected back to the boundary based on half the calculated MCL coordination distance. Therefore, the licensed area boundary psfd trigger is somewhat higher than the psfd at a victim receiver based on the acceptable I/N. Consequently, a higher level of interference potential exists over parts of the neighboring licensed area, but the acceptability of this situation can be assessed by examining the probability of harmful interference.

E.3 Application of the coordination distance and psfd triggers

An operator calculates the required EIRP dependant coordination distance based on maintaining the psfd boundary requirement using a free-space, LOS calculation. If his or her intended deployment falls outside the required coordination zone, then he or she needs take no further action. If his or her intended deployment falls within the coordination zone, then he or she needs to carry out a more complex calculation of the resulting psfd at (or beyond) the licensed area boundary. This should take into account all relevant propagation factors, terrain, and clutter to establish whether his or her deployment will result in a psfd greater than the limit. For assessing subscriber station interference, attention needs to be paid to the possibility of uncorrelated rain fading in certain directions.

If the psfd threshold is exceeded then he or she should take steps to reduce the EIRP in the direction of the boundary by either repointing or introducing further blockage. Alternatively, depending on the demography of the adjacent licensed area there might be the possibility of negotiation with the adjacent operator to agree a new “virtual” license area boundary for the purposes of coexistence.

E.4 Trigger values

Using the methods detailed above and based upon the parameter values below, the following example psfd levels have been derived for application at the licensed area boundary in the frequency bands identified:

28 GHz Band;	–102.5 (dBW/m^2)/MHz
40 GHz Band;	–98.5 (dBW/m^2)/MHz

These are associated with the following coordination distance requirements based on the typical EIRPs detailed below such that any deployment within this distance of the boundary requires a check of the resultant boundary psfd. They are dependant upon the type of station:

For PMP hub (base station)

28 GHz Band;	27.5 km
40 GHz Band;	18 km

For subscriber stations

28 GHz Band;	16 km
40 GHz Band;	10 km

Statistical modelling of multiple interferer scenarios has shown that when allowance is made for the limited probability of a line of sight path between interferers and victim, and of the deployment of down tilted base station antennas in PMP networks, application of these limits can ensure substantially interference free coexistence between adjacent service areas.

E.5 Worst-case interferer calculations

E.5.1 Base station to base station

The basic link budget equation is as follows:

$$P_{\text{rec}} = EIRP_{\text{tx}} - FSPL - L_{\text{atmos}} + G_{\text{rec}}$$

where:

P_{rec} is the interference power at the receiver input.
$FSPL$ is the free space path loss = $20 \log (4\pi R_{\text{min}}/\lambda)$.
L_{atmos} is the atmospheric loss ($0.16R_{\text{min}}$dB at 42 GHz or $0.12R_{\text{min}}$ dB at 28 GHz).
G_{rec} is the receiver antenna gain in the direction of the interferer.
R_{min} is the minimum separation distance.

To meet the interference criterion for each band ($I/N = -10$ dB):

R_{min} = 36 km for 40.5 GHz, therefore coordination distance = 18 km.
R_{min} = 55 km for 27.5 GHz, therefore coordination distance = 27.5 km.

Antenna aperture:

$$\begin{aligned} A_{\text{e}} &= G_{\text{rec}} + 10\log(\lambda^2/4\pi) \\ &= -35.24 \text{ dBm}^2 \text{ at 27.5 GHz and a 15 dBi antenna gain.} \\ &= -38.60 \text{ dBm}^2 \text{ at 40.5 GHz and a 15 dBi antenna gain.} \end{aligned}$$

Power spectral flux density:

$psfd = P_{rec} - A_e$

P_{rec} at 18 km for 40.5 GHz = –137.1 dBW/MHz
P_{rec} at 27.5 km for 27.5 GHz = –137.7 dBW/MHz

Therefore boundary psfd:

For 27.5 GHz = –102.5 (dBW/m^2)/MHz
For 40.5 GHz = –98.5 (dBW/m^2)/MHz

E.5.2 Subscriber station interference

A maximum cell size R_{max}, needs to be determined based upon the assumed parameter values. From the maximum base station EIRP, subscriber station antenna gain and nominal subscriber receiver operating level a maximum path attenuation can be calculated.

Maximum path attenuation (FSPL + Atmospheric Loss + Rain Fade) = 153 dB.

Therefore maximum cell size:

R_{max} = 2.6 km for 40.5 GHz
R_{max} = 4.1 km for 27.5 GHz

It is assumed that worst case interference occurs when the subscriber station is at the cell edge and looking towards a serving base station at the boundary and beyond to a victim base station located within the neighboring network by the coordination distance.

Therefore worst case distance:

For 40.5 GHz = 20.6 km
For 27.5 GHz = 31.6 km

Max EIRP = 11.5 dBW/MHz, assuming the path in the cell is subject to rain fading. The effective EIRP at the victim is assumed to be reduced by the cell radius multiplied by the rain attenuation figures assumed for the frequency band under consideration.

Interfering power:

$P_{\text{rec}} = EIRP_{\alpha} - FSPL - L_{\text{atmos}} + G_{\text{rec}}$

Therefore, the interfering power at the victim base station is as follows:

–147.4 dBW/MHz at 27.5 GHz
–146.3 dBW/MHz at 40.5 GHz

These two figures are both marginally below the interference limit assumed for each frequency band.

Allowing for the effective EIRP after rain fading, coordination distances can be calculated.

Coordination distance:

13 km at 27.5 GHz
8 km at 40.5 GHz

However, it is possible that a combination of nondirect alignment close to bore-sight and of rain fading not affecting the interference path could cause higher EIRP in the direction of the boundary.

Assuming a maximum EIRP from the subscriber station and a 10° off-boresight angle towards the boundary, then by reference to the assumed antenna pattern, the maximum EIRP towards the boundary could be –5.5 dBW/MHz.

Therefore, coordination distance:

16 km at 27.5 GHz
10 km at 40.5 GHz

E.6 Parameter values used for trigger derivation and simulations

For the purposes of the calculating appropriate coordination zones, psfd trigger levels, and Monte Carlo testing, the following system, deployment, and propagation parameter values were assumed:

Assumed parameters for interference analysis:

Nominal channel bandwidth:	28 MHz
Base station EIRP:	15 dBW = 0.5 dB W/MHz
Base station antenna gain:	15 dBi
Base station antenna radiation pattern:	EN 301 215 class CS2
Base Station antenna downtilt:	9°
Subscriber station EIRP:	26 dBW = 11.5 dBW/MHz
Subscriber station ATPC assumed:	Rx input level maintained at 5 dB above the threshold for BER = 10^{-6}.
Subscriber station antenna gain:	32 dBi (PMP); 26 dBi (mesh)
Subscriber station antenna 3 dB beam width:	4° (PMP); 9° (mesh)
Subscriber station antenna radiation pattern:	EN 301 215 class TS1
Subscriber station receiver threshold (10^{-6} BER):	–111 dBW (QPSK) = –125.5 dBW/MHz
Nominal operating level (threshold +5 dB):	–106 dBW
Receiver noise figure:	8 dB (42 GHz) 7 dB (28 GHz)
Interference limit (kTBF – 10 dB):	–146 dBW/MHz (42 GHz) –147 dBW/MHz (28 GHz)
Atmospheric attenuation:	0.16 dB/km at 42 GHz 0.12 dB/km at 28 GHz
Rain attenuation:	7.2 dB/km at 42 GHz 4.6 dB/km at 28 GHz

Annex F

(informative)

Industry Canada coordination process

In Canada, a dual power flux density (pfd) level coordination process is used to facilitate coordination of fixed broadband wireless access systems (BWA) operating in the 24/28/38 GHz bands. The Canadian dual pfd metric is identical in principle and value with the dual psfd metric utilized in Recommendation 5 of 4.2 and the discussion in 7.3 because the Canadian psfd metric is always measured in a bandwidth of 1 MHz. The dual pfd coordination process was developed to allow for flexible deployment of fixed BWA systems without unnecessary constraints. In addition, the dual pfd process would be used only in cases where mutual sharing arrangements between fixed BWA operators do not exist. The following is an excerpt[10] of the coordination process being used in Canada for the 24 GHz range as shown in the document Standards Radio System Plan 324.25 (SRSP 324.25) [B12]. (This document, along with the SRSP for the 28 GHz band (SRSP 325.35) [B13], SRSP for the 38 GHz band (SRSP 338.6) [B14], as well as related Radio Standards Systems Plan (RSS 191) [B11] can be found at http://strategis.ic.gc.ca/spectrum).

> **6. Intersystem coordination**
>
> **6.1 International coordination**
>
> 6.1.1 Usage of the band 24.25 - 25.25 GHz near the Canada/U.S. border is subject to the provisions of the Interim Arrangement Concerning the Sharing Between Canada and the United States of America on Broadband Wireless Systems in the Frequency Bands 24.25–24.45 GHz, 25.05–25.25 GHz, and 38.6–0.0 GHz. (Refer to Section 3 of this document.)
>
> **6.2 Domestic Coordination**
>
> 6.2.1 Domestic coordination is required between licensed service areas[11] where the shortest distance between the respective service area boundaries is less than 60 km[12]. The operators are encouraged to arrive at mutually acceptable sharing agreements that would allow for the provision of service of each licensee within its service area to the maximum extent possible.
>
> 6.2.2 When a sharing agreement does not exist or has not been concluded between operators whose service areas are less than 60 km apart, the following coordination process shall be employed:
>
> 6.2.2.1 Operators are required to calculate the power flux density (pfd) at the service area boundary of the neighboring service area(s) for the transmitting facilities. Power flux density is calculated using accepted engineering practices, taking into account such factors as propagation loss, atmospheric loss, antenna directivity toward the service area boundary, and curvature of the Earth. The pfd level at the service area boundary shall be the maximum value for elevation points up to 500 m above local terrain elevation. (See Appendix C for a sample calculation of a pfd level.)

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[10] The text is subject to change without notice. Readers should consult Industry Canada for the most current standards.

[11] Appendix A is provided as a guide to determine which service areas should be considered for coordination.

[12] In the event an operator uses sites of very high elevations relative to local terrain that could produce interference to service areas beyond 60 km, the operator shall coordinate with the affected licensee(s).

6.2.2.2 Deployment of facilities that generate a pfd less than or equal to –114 dBW/m^2 in any 1 MHz (pfd A) at the other service area boundaries is not subject to any coordination requirements.

6.2.2.3 Deployment of facilities that generate a pfd greater than pfd A (–114 dBW/m^2 in any 1 MHz), but less than or equal to –94 dBW/m^2 in any 1 MHz (pfd B) at the other service area boundaries, is subject to successful coordination between the affected licensees in accordance with the following coordination process:

6.2.2.3.1 The operator must notify the respective licensee(s) of their intention to deploy the facility(ies) and submit the information necessary to conduct an interference analysis.

6.2.2.3.2 The recipient of the notification must respond within 30 calendar days to indicate any objection to the deployment. Objection may be based on harmful interference to existing systems[13] only.

6.2.2.3.3 If there is no objection raised, the deployment may proceed.

6.2.2.3.4 If an objection is raised, the respective licensees must work in collaboration to reach a suitable agreement before the deployment of facilities. It is expected that the time frame to develop such an agreement should not exceed 30 calendar days.

6.2.2.3.5 Proposed facilities must be deployed within 120 calendar days of the conclusion of coordination, otherwise coordination must be reinitiated as per section 6.2.2.

6.2.2.4 Deployment of facilities that generate a pfd greater than –94 BW/m^2 in any 1 MHz (pfd B) at the other service area boundaries is subject to successful coordination between the affected licensees.

6.2.2.5 The above process is described graphically in Appendix B of this document.

6.2.3 In any event, licensees are expected to take full advantage of interference mitigation techniques such as antenna discrimination, polarization, frequency offset, shielding, site selection, and/or power control to facilitate the coordination of systems.

6.2.4 All results of analysis on pfd and agreements made between licensees must be retained by the licensees and made available to the Department on request.

6.2.5 If a licence is transferred, the sharing agreement(s) developed between the former licensees shall remain in effect until superseded by a new agreement between the licensees.

6.2.6 In the event a satisfactory agreement or successful coordination between the licensees is not reached, the Department should be informed. In these cases, the Department may impose appropriate technical limitations to facilitate reasonable implementation of systems.

6.2.7 Licensees shall ensure that the pfd at the boundary of unlicensed neighboring service areas does not exceed pfd B.

6.2.8 While coordination between adjacent block licensees operating in the same vicinity may not be required in most cases, licensees may agree to coordinate certain installations to avoid interference

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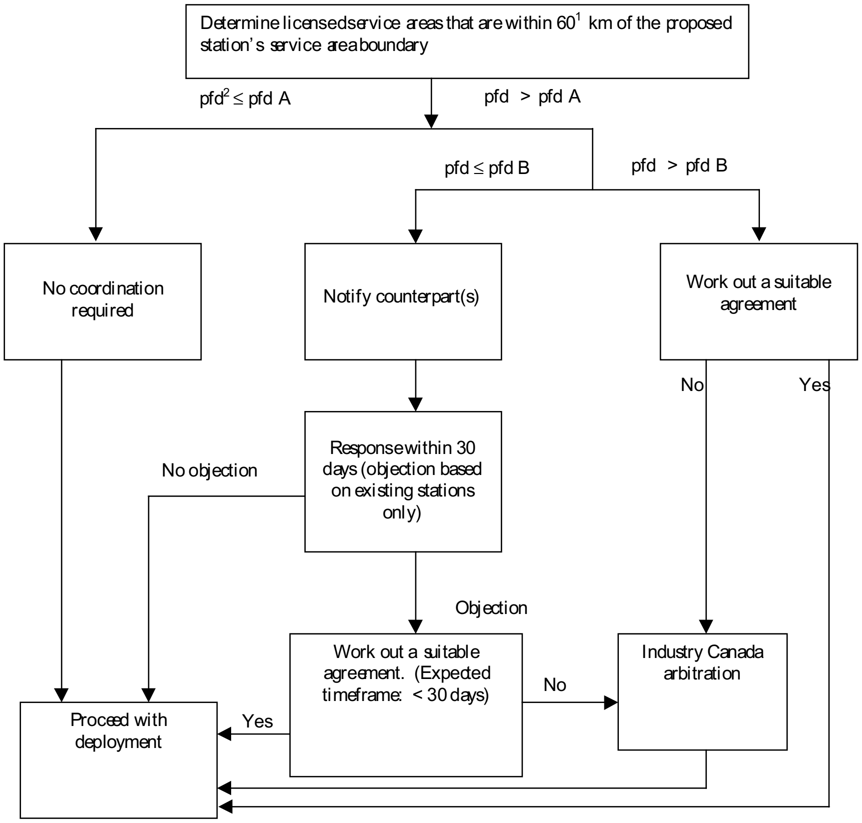
[13] Existing systems include systems that are operational prior to receipt of the notification, or systems that have previously been coordinated.

Appendix A (*not reproduced*)

Appendix B

The process to determine whether coordination is required for cases where a sharing agreement between the licensees has not been concluded. The proposed coordination process is shown in Figure F.1



[1] In the event an operator using sites of very high elevations relative to local terrain that could produce interference to service area beyond 60 km, this operator shall coordinate with the affected licensee(s).

[2] The pfd is calculated at the service area boundary of the respective counterpart(s).

Figure F.1—Proposed coordination process

Annex G

(informative)

Bibliography

[B1] CEPT/ERC Recommendation 74-01, "Spurious Emissions."

[B2] CEPT/ERC Report 099, "Preliminary Report on the analysis of the coexistence of two FWA cells in the 24.5–26.5 GHz and 27.5-29.5 GHz bands."

[B3] ETSI DEN/TM 04097, "Fixed Radio Systems; Radio equipment for use in Multimedia Wireless Systems (MWS) in the band 40.5 GHz to 43.5 GHz."

[B4] ETSI EN 301 213, parts 1–3, "Point-to-Multipoint digital radio systems in frequency bands in the range 24,5 GHz to 29,5 GHz using different access methods."

[B5] ETSI EN 301 215-1, "Point-to-Multipoint Antennas: Antennas for point-to-multipoint fixed radio systems in the 11 GHz to 60 GHz band; Part 1: General aspects."

[B6] ETSI EN 301 215-2, "Point to Multipoint Antennas: Antennas for point-to-multipoint fixed radio systems in the 11 GHz to 60 GHz band; Part 2: 24 GHz to 30 GHz."

[B7] ETSI TR101 177 V1.1.1, "Broadband Radio Access Networks (BRAN); Requirements and architectures for broadband fixed radio access networks (HIPERACCESS)."

[B8] ETSI TR101 853 V1.1.1 (2000-10), "Rules for Coexistence of P-P and P-MP systems using different access methods in the same frequency band."

[B9] IEEE 100, The Authoritative Dictionary of IEEE Standards Terms, Seventh Edition.

[B10] Industry Canada Interim Arrangement Concerning the Sharing between Canada and the United States of America on Broadband Wireless Systems in the Frequency Bands 24.25–24.45 GHz, 25.05–25.25 GHz, and 38.6–40.0 GHz.

[B11] Industry Canada Radio Standards Specifications, RSS-191, "Local Multi Point Communication Systems in the 28 GHz Band; Point-to-Point and Point-to-Multipoint Broadband Communication Systems in the 24 GHz and 38 GHz Bands."

[B12] Industry Canada Standard Radio Systems Plan (SRSP) 324.25, "Technical Requirements for Fixed Radio Systems Operating in the Bands 24.25 - 24.45 GHz and 25.05–25.25 GHz."

[B13] Industry Canada Standard Radio Systems Plan (SRSP) 325.35, "Technical Requirements for Local Multipoint Communication Systems (LMCS) Operating in the Band 25.35–28.35 GHz."

[B14] Industry Canada Standard Radio Systems Plan (SRSP) 338.6, "Technical Requirements for Fixed Radio Systems Operating in the Band 38.6–40.0 GHz."

[B15] ITU-R Recommendation F.746-1, "Radio frequency channel arrangements for fixed services in the range 22.0 GHz to 29.5 GHz."

[B16] ITU-R Recommendation F.758-2, "Considerations in the development of criteria for sharing between the terrestrial fixed service and other services."

[B17] ITU-R Recommendation F.1191, “Bandwidths and unwanted emissions of digital radio relay systems.”

[B18] ITU-R Recommendation F.1249-1, “Maximum equivalent isotropically radiated power of transmitting stations in the fixed service operating in the frequency band 25.25–27.5 GHz shared with the intersatellite service.”

[B19] ITU-R Recommendation F.1399, “Vocabulary of terms for wireless access.”

[B20] ITU-R Recommendation P.452, “Prediction procedure for the evaluation of microwave interference between stations on the surface of the Earth at frequencies above about 0.7 GHz.”

[B21] ITU-R Recommendation P.676-4, “Attenuation by atmospheric gases.”

[B22] ITU-R Recommendation P.838, “Specific attenuation model for rain for use in prediction methods.”

[B23] ITU-R Recommendation P.840-3, “Attenuation due to clouds and fog.”

[B24] ITU-R Recommendation P.1410, “Propagation data and prediction methods required for the design of terrestrial broadband millimetric radio access systems”

[B25] Radio Advisory Board of Canada (RABC) RABC Publication 99-2, “RABC Study Leading to a Coordination Process for Systems in the 24, 28 and 38 GHz Bands.”

The following documents, while not directly referenced in the text, are related and may be helpful to the reader:

[B26] CEPT Recommendation T/R 13-02, “Preferred channel arrangements for the Fixed Services in the range 22.0–29.5 GHz.”

[B27] ETSI EN 301 215-3, “Characteristics of Multipoint Antennas for use in the Fixed Service in the band 40.5 GHz to 43.5 GHz.”

[B28] IEC Publication 154-2, “Flanges for wave guides, rectangular.”

[B29] ITU-R Recommendation P.526-6, “Propagation by diffraction.”

[B30] ITU-R Recommendation P.530-8, “Propagation data and prediction methods required for the design of terrestrial line-of-sight systems.”

[B31] ITU-R Recommendation P.837-1, “Characteristics of precipitation for propagation modeling.”

[B32] ITU-R Recommendation P.841-1, “Conversion of annual statistics to worst–month statistics.”