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(Revision of IEEE Std 802.16.2-2001)

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IEEE Recommended Practice for Local and metropolitan area networks

Coexistence of Fixed Broadband Wireless Access Systems

IEEE Computer Society
and the
IEEE Microwave Theory and Techniques Society

Sponsored by the
LAN/MAN Standards Committee

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Figure 2 and Figure 3 from ETSI EN 301 390 V1.1.1, 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.

Abstract: This recommended practice provides recommendations for the design and coordinated deployment of fixed broadband wireless access systems in order to control interference and facilitate coexistence. It analyzes appropriate coexistence scenarios and provides guidance for system design, deployment, coordination, and frequency usage. It generally addresses licensed spectrum between 2 GHz and 66 GHz, with a detailed emphasis on 3.5 GHz, 10.5 GHz, and 23.5 – 43.5 GHz.

Keywords: coexistence, fixed broadband wireless access (FBWA), interference, local multipoint distribution service (LMDS), millimeter waves, multichannel multipoint distribution service (MMDS), microwaves, multipoint (MP), point-to-multipoint (PMP), radio, wireless metropolitan area network (WirelessMAN™) standard

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Introduction

(This introduction is not a part of IEEE Std 802.16.2-2003, IEEE Recommended Practice for Local and Metropolitan Area Networks—Coexistence of Fixed Broadband Wireless Access Systems.)

This recommended practice revises IEEE Std 802.16.2™-2001. The original document covered 10–66 GHz frequencies in general, with a focus on 23.5–43.5 GHz frequencies. The activity paralleled the project in the IEEE 802.16 Working Group to develop IEEE Std 802.16™-2001, which specified the WirelessMAN air interface from 10 GHz to 66 GHz. As the Working Group expanded the scope of the WirelessMAN air interface to include 2–11 GHz frequencies, in the project leading to the IEEE Std 802.16a™ amendment, the working group took up the task of developing a parallel extension of its coexistence work to include 2–11 GHz frequencies. This revision includes the results of that effort, along with additional material on coexistence with point-to-point (PTP) systems.

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Interpretations

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

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This recommended practice was developed by the IEEE 802.16 Working Group on Broadband Wireless Access, which is responsible for wireless metropolitan area network (WirelessMAN™) standards. The IEEE 802.16 Working Group had the following officers:

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Coexistence of Fixed Broadband Wireless Access Systems

1. Overview

This recommended practice provides recommendations for the design and coordinated deployment of fixed broadband wireless access (FBWA) systems in order to control interference and facilitate coexistence among these systems and with other applicable systems that may be present.

Due to the distinctly different physical behavior over the frequency range to which this recommended practice is applicable, this document addresses several such frequency subranges separately. Specifically, the following topics are addressed:

- Coexistence among FBWA systems operating in 23.5–43.5 GHz frequencies
- Coexistence of FBWA systems with point-to-point (PTP) systems operating in 23.5–43.5 GHz frequencies
- Coexistence among FBWA systems operating in 2–11 GHz licensed bands

For each of the above topics, the following aspects are addressed:

- Summary of applicable coexistence recommendations and guidelines.
- Overview of the systems for which coexistence criteria are analyzed, including system architecture and medium overview.
- Equipment design parameters relevant to the analyses.
- Methodology to be used in the deployment and coordination of systems.
- Interference and propagation evaluation examples, indicating some of the models, simulations, and analyses used in the preparation of this recommended practice.
- Possible mitigation techniques in case of co-channel (CoCh) interference between systems operating in adjacent areas or in case of undesired signals caused by natural phenomena and other unintentional sources.

The intent of this recommended practice is to define a set of consistent design and deployment recommendations that promote coexistence for FBWA systems and for PTP systems that share the same bands. The recommendations have been developed and substantiated by analyses and simulations specific to the deployment and propagation environment appropriate to terrestrial FBWA intersystem interference experienced between operators licensed for FBWA and operators of PTP link systems sharing the same bands. 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.

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 FBWA industry. The recommendations in 5.2, 6.1, and 7.2 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.

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

1.1 Scope

This recommended practice revises IEEE Std 802.16.2™-2001. In particular, it specifies extensions and modifications addressing two distinct topics. The first is coexistence between multipoint (MP) systems and PTP systems in the 10–66 GHz frequency range. The second is coexistence among FBWA systems operating in licensed bands within the 2–11 GHz frequency range. Updates to the existing content are also considered.

1.2 Purpose

The purpose of this recommended practice is to provide coexistence guidelines to license holders, service providers, deployment groups, and system integrators. The specifications will facilitate the deployment and operation of FBWA systems while minimizing the need for case-by-case coordination.

2. Normative references

This recommended practice shall be used in conjunction with the following:

ETSI EN 301 390 (2003-11), 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]

ITU-R Recommendation F.1509 (02/01): 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.[2]

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[1] ETSI standards are available from publication@etsi.fr and http://www.etsi.org/eds/eds.htm.

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

3. Definitions and Abbreviations

For the purposes of this recommended practice, the following terms and definitions apply. *The Authoritative Dictionary of IEEE Standards Terms*, Seventh Edition [B30][3], should be referenced for terms not defined in this clause.

Other standards (e.g., ITU-R Recommendation F.1399-1 (2001-05) [B37]) 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 frequency range(s) over which an operator is permitted to operate radio transmitters and receivers.

3.1.2 automatic transmit power control (ATPC): A technique used in broadband wireless access (BWA) systems to adaptively adjust the 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 stations (SSs).

3.1.4 block bandwidth (*B*): The contiguous authorized bandwidth available to an operator.

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

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

3.1.7 channel bandwidth: For single carriers, the bandwidth assigned to individual carriers within a block. This may differ for different carriers within a block. The occupied bandwidth of a carrier within a channel may be less than or equal to the bandwidth of a channel. For a multicarrier transmission using a common amplifier stage, the sum of all composite carriers.

3.1.8 cross-polar discrimination (XPD): For a given direction, the difference in decibels between the peak co-polarized gain of the antenna and the cross-polarized gain of the antenna.

3.1.9 dBi: In the expression of antenna gain, the number of decibels of gain of an antenna referenced to the 0 dB gain of a free-space isotropic radiator.

3.1.10 digital modulation: 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.

3.1.11 downlink: The direction from a base station (BS) to the subscriber station (SS).

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

3.1.13 fixed wireless access: Wireless access application in which the location of the subscriber station (SS) and the base station (BS) are fixed in location.

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[3] The numbers in brackets correspond to the numbers of the bibliography in Annex A.

3.1.14 frequency block: A contiguous portion of spectrum within a subband or frequency band, typically assigned to a single operator. A collection of frequency blocks may form a subband and/or a frequency band.

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

3.1.16 frequency reuse: 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 guard band: Spectrum identified between adjacent operator frequency blocks, specifically for providing some isolation between the systems deployed in these neighboring frequencies.

3.1.18 harmonized transmissions: The use, by multiple operators, of a compatible transmission plan so that the base stations (BSs) from different operators can share an antenna site and minimize interference. For frequency division duplex (FDD) systems, this implies that each operator's BS transmits in the same frequency subblock (typically on a different channel) and that each terminal transmits in the corresponding paired subblock. For time-division duplex (TDD) systems, harmonization implies frame, slot, and uplink/downlink synchronization.

3.1.19 intercell link: A radio link used to interconnect two or more base station (BS) sites.

3.1.20 line of sight (LOS): Condition in which the signal path is >60% clear of obstructions within the first Fresnel Zone.

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

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

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

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

3.1.25 narrowband: Operating with a bit rate not exceeding 64 kbit/s.

3.1.26 net filter discrimination (NFD): The ratio between the power transmitted by the interfering system and the portion that could be measured after the receiving filter of the useful system.

3.1.27 non line of sight (NLOS): Condition in which the signal path is <40% clear of obstructions within the first Fresnel Zone.

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

3.1.29 occupied bandwidth (B_O): For a single carrier, B_O 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:

$$B_{\mathbf{OM}} = 1/2\, B_{\mathrm{OU}} + 1/2\, B_{\mathrm{OL}} + (F_{0\mathrm{U}} - F_{0\mathrm{L}})$$

where

B_{OM} = occupied bandwidth of the multicarrier system,
B_{OU} = single-carrier occupied bandwidth of the uppermost subcarrier,
B_{OL} = single-carrier occupied bandwidth of the lowermost subcarrier,
$F_{0\mathrm{U}}$ = center frequency of the uppermost subcarrier,
$F_{0\mathrm{L}}$ = center frequency of the lowermost subcarrier.

NOTE—This multicarrier definition will give a bandwidth that 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.

3.1.30 out-of-block (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.

3.1.31 point-to-multipoint (PMP): In wireless systems, a topology where a base station (BS) services multiple, geographically separated subscriber stations (SSs), and each SS is permanently associated with only one BS.

3.1.32 point-to-point (PTP): A topology in which a dedicated radio link is maintained between two stations.

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

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

3.1.35 radiation pattern envelope (RPE): RPE is an agreed mask defining an upper bound that antenna radiation patterns are expected to fit beneath. The RPE is usually presented as a plot or a table, representing a function of relative radiation power density versus angular offset in a defined plane with respect to an axis along the antenna direction exhibiting maximum radiation (antenna boresight). The radiation power density is usually expressed in dB relative to the maximum radiation power density on antenna boresight in the primary polarization orientation. The RPE is usually applicable over a defined frequency range for the antennas under consideration.

3.1.36 repeater station (RS): A station other than the base station (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 RS.

3.1.37 second adjacent channel (AdjCh): Next channel beyond the AdjCh.

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

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

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

NOTE—This definition is adopted for use in this recommended practice. For a more general definition, see ITU Radio Regulations [B33].

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

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

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

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

3.1.45 uplink: The direction from a subscriber station (SS) to the base station (BS).

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

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

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

3.1.49 %KO: Percentage area of a point-to-multipoint (PMP) cell area where interference may afflict or arise from subscriber station (SS) and “knock out” the radio receiver(s).

3.2 Abbreviations

AA	adaptive antenna
AdjCh	adjacent channel
ATPC	automatic transmit power control
AZ	azimuth
BER	bit error ratio
B_O	occupied bandwidth
BS	base station
BW	bandwidth
BWA	broadband wireless access
CDF	cumulative distribution function
CDMA	code division multiple access
C/I	carrier-to-interference ratio
C/N	carrier-to-noise ratio
$C/(N+I)$	carrier-to-(noise and interference) ratio
CoCh	co-channel
Co-Pol	co-polar
CS	channel separation
CW	continuous wave
dBc	decibels relative to the carrier level
dBi	see 3.1.9
DRS	data relay satellite
DS-3	44.736 Mbit/s line rate
D/U	desired-carrier–to–undesired-carrier ratio
EL	elevation
EIRP	equivalent isotropically radiated power

FBWA	fixed broadband wireless access
FDD	frequency division duplex
FDMA	frequency division multiple access
FSPL	free space path loss
GSO	geostationary orbit
HP	high performance
IA	interference area
ICL	interference coupling loss
I/N	interference–to–thermal-noise ratio
ISOP	interference scenario occurrence probability
LMCS	local multipoint communication system
LMDS	local multipoint distribution service
LOS	line of sight
MAN	metropolitan area network
MCL	minimum coupling loss
MMDS	multichannel multipoint distribution system
MP	multipoint
MP-MP	multipoint-to-multipoint
MWS	multimedia wireless systems
NFD	net filter discrimination
NLOS	non line of sight
OC-3	155.52 Mbit/s line rate
OFDM	orthogonal frequency division multiplexing
OFDMA	orthogonal frequency division multiple access
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
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
TE	terminal equipment
Tx	transmit
XPD	cross-polar discrimination
X-Pol	cross-polar

4. System overview

Broadband wireless access (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 recommended practice, broadband transmission generally refers to transmission rate of greater than 1.5 Mbit/s, though many BWA networks support significantly higher data rates.

The networks operate transparently, so users are not aware that services are delivered by radio. A typical FBWA 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 (i.e., customer) 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 results in a number of benefits, including rapid deployment and relatively low up-front costs.

4.1 System architecture

FBWA systems often employ MP architectures. MP includes point-to-multipoint (PMP) and mesh. The IEEE 802.16 Working Group on Broadband Wireless Access has developed a standard (IEEE Std 802.16™-2001 [B31], IEEE Std 802.16c™-2002 [B32], and IEEE Std 802.16a™-2003 [B87]) containing a fully specified air interface for PMP (2–66 GHz) and mesh (2–11 GHz) systems. Similar standards have been developed within the HIPERACCESS and HIPERMAN working groups of the ETSI Broadband Radio Access Networks Project. In addition, a number of proprietary FBWA systems exist for which the air interface is not standardized.

FBWA systems typically include base stations (BSs), subscriber stations (SSs), terminal equipment (TE), core network equipment, intercell links, repeater stations (RSs), and possibly other equipment. A reference FBWA 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. A FBWA system contains at least one BS and a number of SS units. In Figure 1, 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 PTP radios that provide a wireless backhaul capability between BSs at rates ranging from DS-3 to OC-3. Such PTP links may operate under the auspices of the PMP license.

Some systems deploy RSs. In a PMP system, RSs are generally used to improve coverage to locations where the BS(s) have no line of sight (LOS) within their normal coverage area(s), or alternatively to extend coverage of a particular BS beyond its normal transmission range. A repeater station (RS) relays information from a BS to one or a group of SSs. It may also provide a connection for a local SS. A repeater station may operate on the same downlink frequencies as the 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 RSs that also provide connections for local subscribers.

The boundary of the FBWA 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 SSs and terminal equipment, may be either standardized or proprietary.

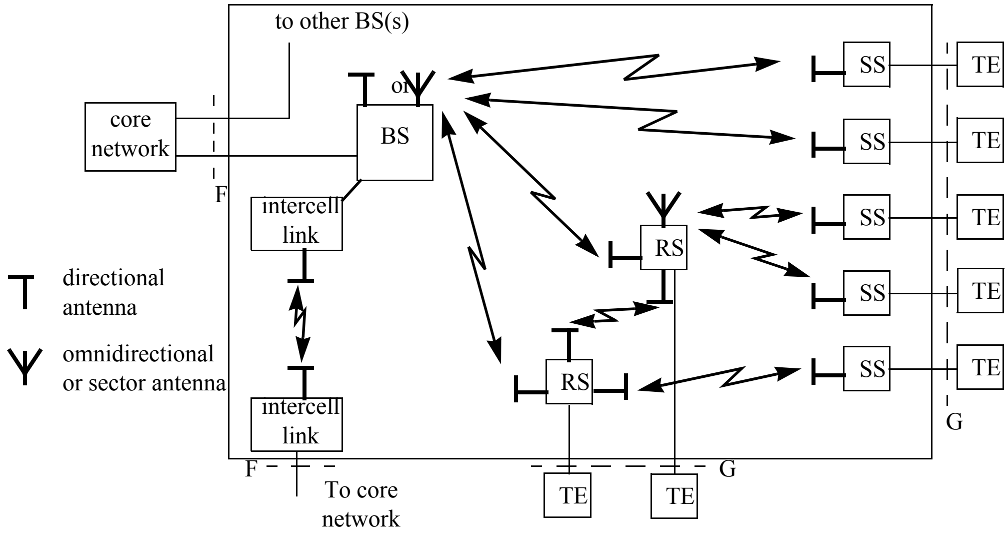

Figure 1—Reference diagram for FBWA systems

4.1.1 PMP systems

PMP systems comprise BSs, SSs and, in some cases, RSs. BSs use relatively wide beam antennas, divided into one or several sectors providing up to 360° coverage with one or more antennas. To achieve complete coverage of an area, more than one BS may be required. The connection between BSs is not part of the FBWA 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 FBWA itself. Routing to the appropriate BS is a function of the core network. SSs use directional antennas, facing a BS and sharing use of the radio channel. This may be achieved by various access methods, including (orthogonal) frequency division, time division, or code division.

4.1.2 Mesh systems

Mesh systems have the same functionality as PMP systems. BSs provide connections to core networks on one side and radio connection to other stations on the other. A SS may be a radio terminal or (more typically) a RS with local traffic access. Traffic may pass via one or more RSs to reach a SS.

4.1.3 Antenna subsystems

The antenna subsystems employed generally depend on the frequency band in use and the system type.

For microwave PMP SSs, the antenna subsystem is generally very highly directive, as LOS is typically required. Microwave mesh SSs typically employ multiple antennas of this type and employ a means for remote alignment.

For millimeter wave BSs, adaptive antenna (AA) systems may be employed to improve performance. For millimeter wave PMP SSs, the antenna subsystem is generally highly directive, though typically less so than for microwave PMP SSs to enable near-LOS and/or non-LOS (NLOS) operation to some extent. Millimeter wave mesh SSs typically use omnidirectional antennas.

4.2 Interference scenarios

4.2.1 Forms of interference

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

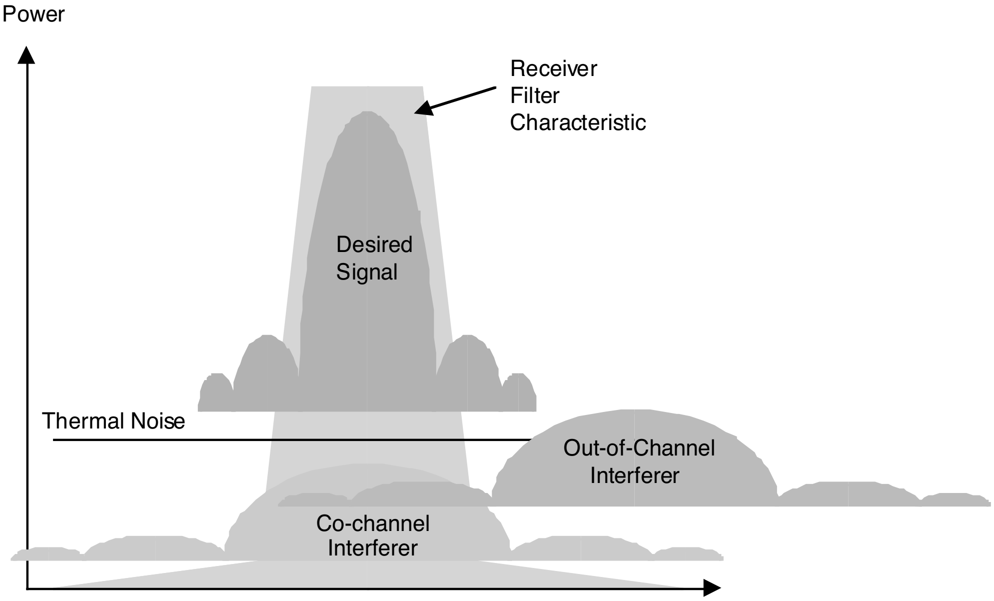

Figure 2—Forms of interference

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

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 CoCh to the desired signal; i.e., within the receiver filter's passband. This can be treated as CoCh interference. It cannot be removed at the receiver; its level is determined at the interfering transmitter. By characterizing the power spectral density (psd) 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 CoCh 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 CoCh 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 CoCh 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.

4.2.2 Acceptable level of interference

A fundamental property of any FBWA 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 in 1 MHz. Interference of –138 dBW in 1 MHz would double the total noise, or degrade the link budget by 3 dB. Interference of –144 dBW in 1 MHz, 6 dB below the receiver thermal noise, would increase the total noise by 1 dB to –137 dBW in 1 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 (pfd) tolerance. In turn, this tolerance can be turned into separation distances for various scenarios.

4.2.3 Interference paths

4.2.3.1 Victim BS

Figure 3 shows main sources of interference where the victim receiver is a FBWA BS, 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.

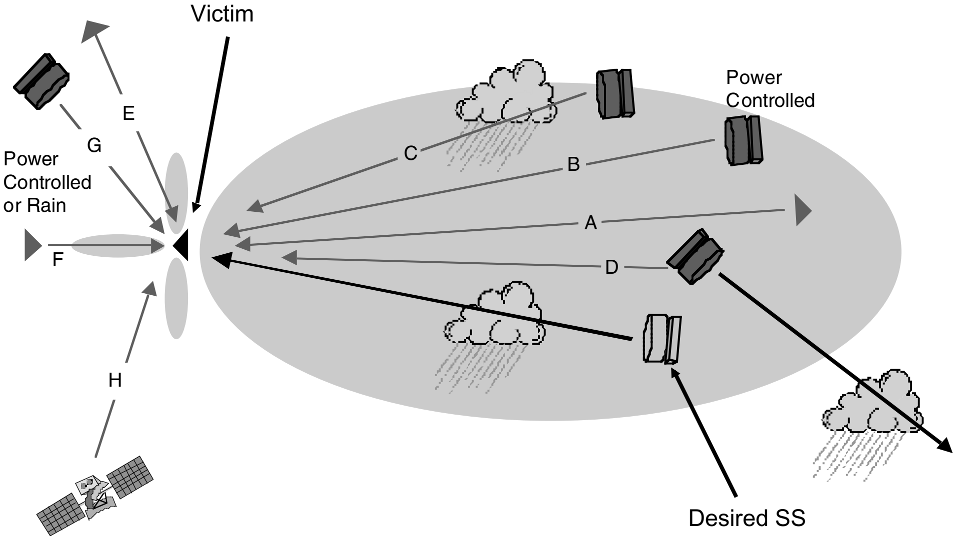

Figure 3—Interference sources to a FBWA BS

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

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 an LOS 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 CoCh BS transmission on frequencies being used for reception at other BSs. This is possible with frequency division duplex (FDD) through cooperative band planning, where vendors agree to use a common subband 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, FBWA PMP systems can safely be assumed to employ uplink adaptive power control at SSs. (Power control is required to equalize the received signal strength arriving at a BS from near and far SSs on adjacent channels (AdjChs). 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 SS 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 turndown 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 PTP 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 to consider either Case B or Case C, but not both. Thus Case B is more conservative with imperfect power control; i.e., the turndown will tend to be less than the fade margin, so the net received power at the victim receiver is several decibels higher than in 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 main lobe 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 turndown 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 FBWA system but a PTP transmitter or a satellite uplink. In these cases, the transmit parameters may be so different from a FBWA SS 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 FBWA 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 interference. 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, only the clear air case need be considered, and an assumption can be made that 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 interference to be considered here are illustrated 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 time-division duplex (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 FBWA system, but could be significant if the interferer is a higher-power PTP 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.

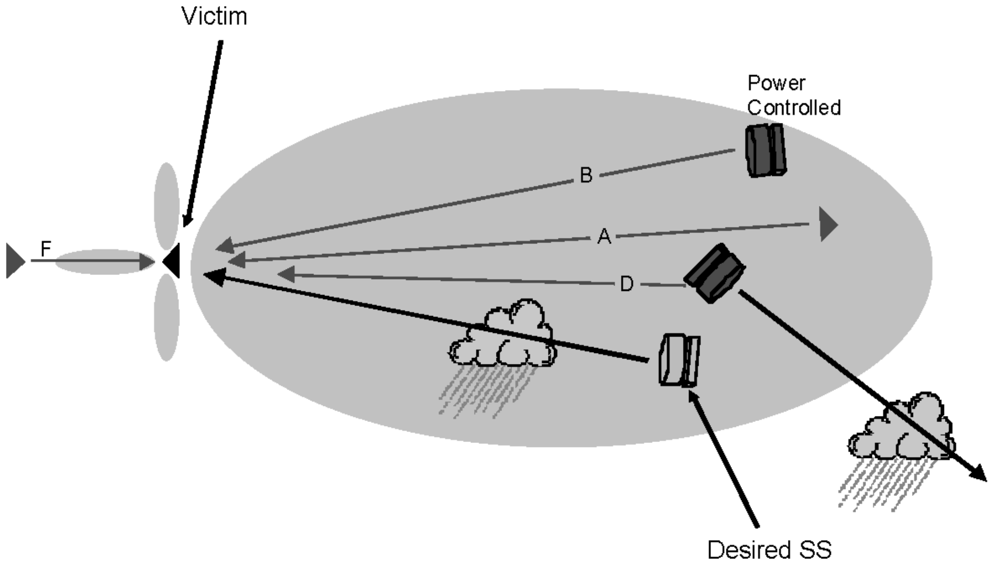

Figure 4—Simplified model for interference to a FBWA BS

4.2.3.2 Victim SS

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

The victim SS 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 SS:

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.

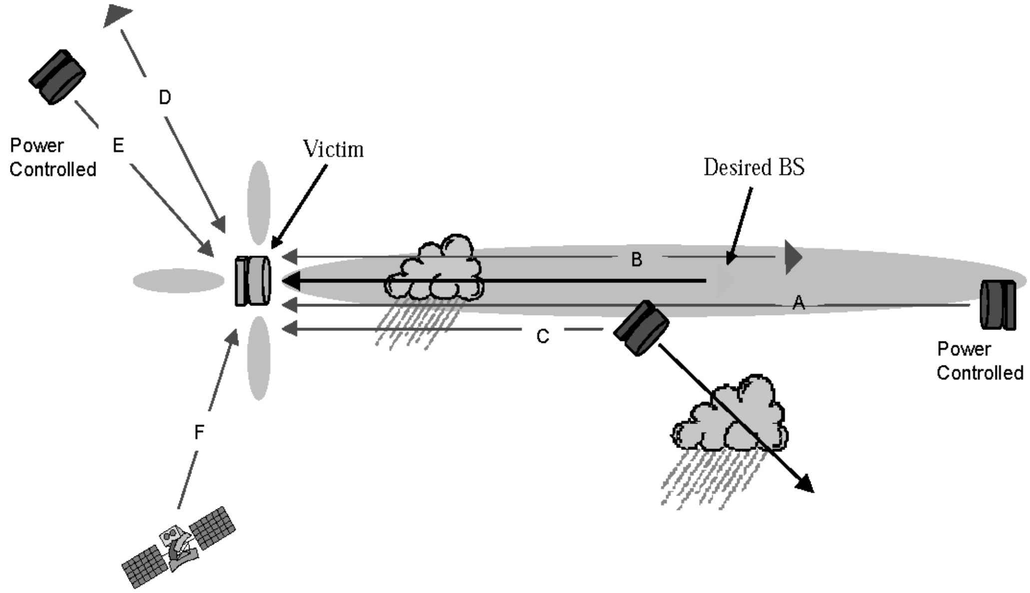

Figure 5—Interference sources to a FBWA SS

Case B covers BS-to-SS interference.

Case C covers the case of a narrow beam transmitter (FBWA or PTP) 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 Case B and Case C for the victim BS, the worst case is likely to be with clear air in the backlobe, rain fading on the path from the desired BS, and the interfering SS pointing directly at the victim SS with maximum power.

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

4.2.3.3 Victim omnidirectional mesh node

The potential interference sources for omnidirectional mesh nodes is shown in Figure 6. As this type of mesh deployment tends to have a relatively small footprint (a few kilometers) and is only feasible on frequencies below 11 GHz, the negative impact of rain cells will be minimal (less than 1 dB). Apart from the omnidirectional interference cases shown in Figure 6, mesh nodes may also employ sector (typically at the mesh BS) and highly directional antennas (possible at the edge of the coverage area), in which case the interference scenarios (particularly Case E and Case F) as specified for the BS (see 4.2.3.1) and all interference scenarios as defined for the SS (see 4.2.3.2) apply, respectively.

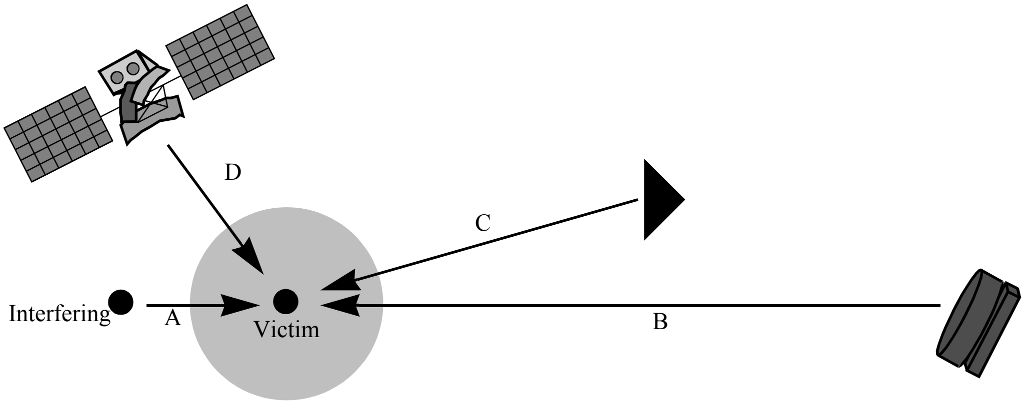

Figure 6—Interference sources to omnidirectional mesh system (BS and SS)

Case A shows mesh-node–to–mesh-node interference. This type of interference may occur in multicell deployments with low spectral reuse and on the boundary of provider coverage areas. In these cases, the victim node could tend to see the aggregate power of several interfering nodes. Compared to the BS-to-BS scenario as outlined in 4.2.3.1, this scenario would tend to be less severe due to the typical low elevation above clutter of this type of deployment, which results in significant NLOS attenuation.

Case B covers interference from a highly directional antenna system into the victim mesh node. The antenna system could be a PMP SS, part of a PTP link, or a mesh node in another cell or from another provider area. Interference energy could be mainly from the main lobe or from a sidelobe. LOS between the interfering and victim antenna is, however, relatively unlikely.

Case C covers interference from a PMP BS into the victim mesh node. This interference may occur on the boundary of coverage areas (same or different provider). The victim node could tend to see the aggregate power of several interfering PMP BSs. Due to the elevation of PMP BSs, LOS may exist. Similar to BS-to-BS interference, this source of interference tends to be most severe for mesh systems.

Case D covers interference from a satellite downlink or stratospheric downlink. This case is not included in this recommended practice.

5. Coexistence of FBWA systems in 23.5 GHz – 43.5 GHz

5.1 Introduction

This clause contains guidelines and recommendations for coexistence between various types of FBWA systems, operating in the 10–66 GHz frequency range. The guidelines and recommendations are supported by the results of a large number of simulations or representative interference cases. The full details of the simulation work are contained in input documents referenced in Annex A.

This clause analyzes coexistence using two scenarios:

- A CoCh scenario in which two operators are in either adjacent territories or territories within radio LOS of each other and have the same or overlapping spectrum allocation
- An 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 FBWA systems, ITU-R Recommendation F.758-2 (2000-05) [B35] 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 recommended practice, this evaluation has been carried out for *I*/*N* = –6 dB.

Subclause 5.8 provides interference mitigation measures that can be utilized to solve coexistence problems. Because of the wide variation in SS and BS 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 recommended practice 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 the recommendations 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 recommended practice to make recommendations that touch on intrasystem matters such as frequency plans and frequency reuse patterns. The results of further work carried out by Industry Canada (IC) are available in B.4.2 and B.6

5.2 Recommendations

5.2.1 Recommendation 1-1

Adopt a criterion of 6 dB below receiver thermal noise (i.e., *I*/*N* ≤ –6 dB) in the victim receiver as an acceptable level of interference from a transmission of an operator in a neighboring area. This recommended practice 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 decibels between carrier-to-noise ratio (*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 1-6 in 5.2.6), this is not always feasible. The actual level of external interference could be higher than the limit stated above and still be neither controlling nor 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.

5.2.2 Recommendation 1-2

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 CoCh interference, this recommended practice introduces the concept of using power spectral flux density (psfd) 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 1-5 (see 5.2.5) and Recommendation 1-6 (see 5.2.6) and in 5.6.

5.2.3 Recommendation 1-3

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 is such that AdjCh operators will be allocated side-by-side frequency channels. This is an especially difficult coexistence problem to resolve without co-location of the operator’s cell sites.

5.2.4 Recommendation 1-4

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 FBWA 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 criterion is viewed to be necessary and appropriate for both systems that conform to this recommended practice and systems that do not.

5.2.5 Recommendation 1-5

(*This recommendation applies to CoCh cases only.*)

Recommendation 1-2 (see 5.2.2) introduced the concept of using psfd 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. If such recommendations are not specified, the following values may be adopted:

The coordination trigger values (see B.2) of –114 dB(W/m^2) in any 1 MHz band (24 GHz, 26 GHz, and 28 GHz bands) and –111 dB(W/m^2) in any 1 MHz band (38 GHz and 42 GHz bands) are employed in the initiative procedure described in Recommendation 1-6 (see 5.2.6). The evaluation point for the trigger exceedance may be at the victim operator’s licensed area boundary, at 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 psfd values which, if present at a typical PMP BS antenna and typical receiver, would result in approximately the –6 dB interference value cited in Recommendation 1-1 (see 5.2.1). 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 interference potential.

5.2.6 Recommendation 1-6

(*This recommendation applies to CoCh cases only*.)

The triggers of Recommendation 1-5 (see 5.2.5) 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 B.4, B.5, and B.6.

5.2.7 Recommendation 1-7

For same-area/AdjCh 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 (OOB) emission levels and in some cases is linked to the probability of interference in given deployment scenarios. Subclause 5.7 provides insight into some methods that can be employed to assess these situations, while 5.8 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.

5.2.8 Recommendation 1-8

Choose antennas for BS and SS appropriate to the degree of coexistence required. Examples of typical antenna masks that are satisfactory in most cases can be found in ETSI EN 301 215-1 (2001-08) [B11] and ETSI EN 301 215-2 (2002-06) [B12]. The coexistence simulations that 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 BS antennas are of a significant but secondary influence. The sidelobe levels of the subscriber antenna are of tertiary importance. In many cases, intrasystem considerations may place higher demands on antenna performance than required for intersystem coordination.

5.2.9 Recommendation 1-9

Limit maximum equivalent isotropically radiated power (EIRP) in accordance with recommendations in 5.5.1.1 and use SS power control in accordance with recommendations in 5.5.1.1.5. The interests of coexistence are served by reducing the amount of EIRP emitted by BSs, SSs, and RSs. The proposed maximum EIRP psd values are significantly less than allowed by some regulatory agencies, but should be an appropriate balance between constructing robust FBWA systems and promoting coexistence.

5.2.10 Recommendation 1-10

In conducting analyses to predict psfd 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 that occurs at some elevation point up to 500 m above local terrain elevation. Equation (B.2) and Equation (B.3) in B.2 should be used to calculate the psfd limits.
c) Actual electrical parameters (e.g., EIRP, antenna patterns) 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., ITU-R Recommendation P.452 (2001-02) [B38]).

5.3 Suggested guidelines for geographical and frequency spacing

Guidelines for geographical and frequency spacing of FBWA systems that would otherwise mutually interfere are given in 5.7.1 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:

- CoCh 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 5.6. 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.

5.4 Medium overview

Electromagnetic propagation over the 10–66 GHz frequency range 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 LOS between transmit (Tx) and Rx 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 that 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 carrier-to-interference ratio (*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.

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, AdjCh	1 guard channel (Notes 3 and 5)
Mesh SSs to PMP SS	Same area, AdjCh	1 guard channel (Note 4)

NOTES
1—The dominant interference path is the path that 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.

5.5 Equipment design parameters

This clause provides recommendations for equipment design parameters that significantly affect interference levels and hence coexistence. Recommendations are made for the following FBWA equipment: BS equipment, SS equipment, RSs, 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 the frequency range 23.5–43.5 GHz, unless otherwise indicated.

5.5.1 Transmitter design parameters

This subclause provides recommendations for the design of both SS and BS transmitters to be deployed in FBWA systems. Recommendations are also made for RSs and intercell links.

5.5.1.1 Maximum EIRP psd 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 EIRP. Since PMP systems span very broad frequency bands and utilize many different channel bandwidths, a better measure of EIRP for coexistence purposes is in terms of psd expressed in dB(W/MHz) rather than simply power in dBW.

The following paragraphs provide recommended EIRP psd limits. These limits apply to the mean EIRP psd 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, IC, and ITU-R regulations and recommendations were reviewed (in particular, US FCC Part 101 section 101.113, IC SRSP 324.25 (2000) [B27], IC SRSP 325.35 (2000) [B28], IC SRSP 338.6 (2000) [B29], ITU-R Recommendation F.1509 (02/01)[4], ITU-R Recommendation F.746-6 (2002-05) [B34], ITU-R Recommendation F.758-2 (2000-05) [B35], and ITU-R Recommendation F.1249-1 (2000-05) [B36]). Table 2 depicts some example regulatory EIRP psd limits.

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)

Table 2—Comparison of typical regulatory EIRP limits and simulation assumptions

Terminal	Example regulatory limits [dB(W/MHz)]	Simulation assumptions [dBW in 1 MHz]
BS	+14	–1.5
SS	+30	+13.5
PTP	+30	+25.0
RS facing BS	+30	Not performed
RS facing SS	+14	Not performed
Mesh	+30	0

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 psd values as suggested in 5.5.1.1.1 through 5.5.1.1.4. 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/AdjCh case (see Recommendation 1-7 in 5.2.7).

5.5.1.1.1 BS

A BS conforming to the recommendations of this recommended practice should not produce an EIRP psd exceeding +14 dBW in 1 MHz. However, it is strongly recommended that a maximum EIRP psd of 0 dBW in 1 MHz be used in order to comply with the one guard channel recommendation for the same-area/AdjCh

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[4] Information on references can be found in Clause 2.

case (see Recommendation 1-7 in 5.2.7). 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 Recommendation F.1509 (02/01) should be observed.

5.5.1.1.2 SS

A SS conforming to the recommendations of this recommended practice should not produce an EIRP psd exceeding +30 dBW in 1 MHz. However, it is strongly recommended that a maximum EIRP psd of +15 dBW in 1 MHz be used in order to comply with the one guard channel recommendation for the same-area/AdjCh case (see Recommendation 1-7 in 5.2.7). Note the stated limits apply to the SS operating under faded conditions (rain attenuation). Power control is recommended for unfaded conditions, as described in 5.5.1.1.5.

NOTE—For the specific subband 25.25–25.75 GHz, the recommended SS EIRP limits as stated in ITU-R Recommendation F.1509 (02/01) should be observed and are summarized as follows:

> Transmitter of an SS in a FBWA system or transmitters of PTP fixed stations: Where practicable, the EIRP psd for each transmitter of an SS of a FBWA system, or transmitters of PTP fixed stations in the direction of any geostationary orbit (GSO) location specified in ITU-R SA.1276 [B46] for a data relay satellite (DRS), should not exceed +24 dBW in any 1 MHz.

5.5.1.1.3 Repeaters (RSs)

Several types of RSs are possible (see 4.1). From the point of view of EIRP psd limits, two recommendations are given, according to the direction faced by the RS and type of antenna used. The first recommended limit applies to situations where a RS uses a sectored or omnidirectional antenna, typically facing a number of SSs. The second case applies where a RS uses a highly directional antenna, typically facing a BS or single SS.

FBWA RS systems deploying directional antennas and conforming to the equipment requirements of this recommended practice should not produce an EIRP psd exceeding +30 dBW in 1 MHz. However, it is strongly recommended that a maximum EIRP psd of +15 dBW in 1 MHz be used in order to comply with the one guard channel recommendation for the same-area/AdjCh case (see Recommendation 1-7 in 5.2.7).

FBWA RSs deploying omnidirectional or sectored antennas and conforming to the equipment requirements of this recommended practice should not produce an EIRP psd exceeding +14 dBW in 1 MHz. However, it is strongly recommended that a maximum EIRP psd of 0 dBW in 1 MHz be used in order to comply with the one guard channel recommendation for the same-area/AdjCh case (see Recommendation 1-7 in 5.2.7).

5.5.1.1.4 In-band intercell links

An operator may employ PTP links that use AdjCh or CoCh frequencies and that are in the same geographical area as a PMP system. If the recommendations for SS EIRP in 5.5.1.1.2 and unwanted emissions in 5.5.1.3 are applied to these links, then they can operate within the coexistence framework described in this recommended practice. If not, then reevaluation of the coexistence recommendations is recommended.

5.5.1.1.5 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 range. Simulation results described in other sections of this recommended practice demonstrate that such a range is necessary in order to facilitate coexistence.

5.5.1.1.6 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 5.5.1.1 should be met.

5.5.1.2 Frequency tolerance or stability

The system should operate within a frequency stability of ±10 ppm.

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 BS. In addition, it is highly recommended that the SS Tx frequency be controlled by using a signal from the downlink signal(s).

5.5.1.3 OOB unwanted emissions

Unwanted emissions produced by an operator’s equipment and occurring totally within an operator’s authorized block bandwidth are relevant only for that operator and are not considered in this recommended practice. Unwanted emissions from an operator that fall into adjacent bands are subject to the constraints set by regulatory authorities. These emission limits may or may not be sufficient to ensure that unacceptable levels of interference are avoided to users of adjacent spectrum.

It is appropriate to define acceptable coexistence criteria in terms of an interference coupling loss (ICL). ICL is the combination of net filter discrimination (NFD) and further isolation obtained by use of system interference mitigation techniques. NFD is represented by the transmission cascade of the out-of-band emissions from the interference source and the filter selectivity of the victim receiver. By itself, isolation obtained through NFD is not necessarily sufficient to ensure that acceptable interference coexistence criteria are achieved.

It is possible to identify ICL limits that define the necessary limits for acceptable coexistence. An example of the identification of such requirements may be found in ETSI TR 101 853 (2000-10) [B16]. Generally speaking, ICL requirements are controlled by the carriers that are located closest to the block edge. Establishment of necessary ICL limits can involve a number of interference mitigation techniques, employed singly or jointly, including

- Employing alternative polarization assignments for carriers located at block edge.
- Reducing the EIRP of carriers located on block edge.
- Establishing BS separation distance limits (BS-to-BS couplings).
- Reducing channel bandwidth assignments for carriers in proximity to block edge.
- Developing a full or partial guard band by not assigning carriers right up to block edge.

By employing a combination of the above techniques, it may be possible to operate without the need for a specific guard band. An operator may then be able to maximize use of spectrum within the assigned frequency block.

5.5.1.4 Unwanted emission levels specified in ETSI standards

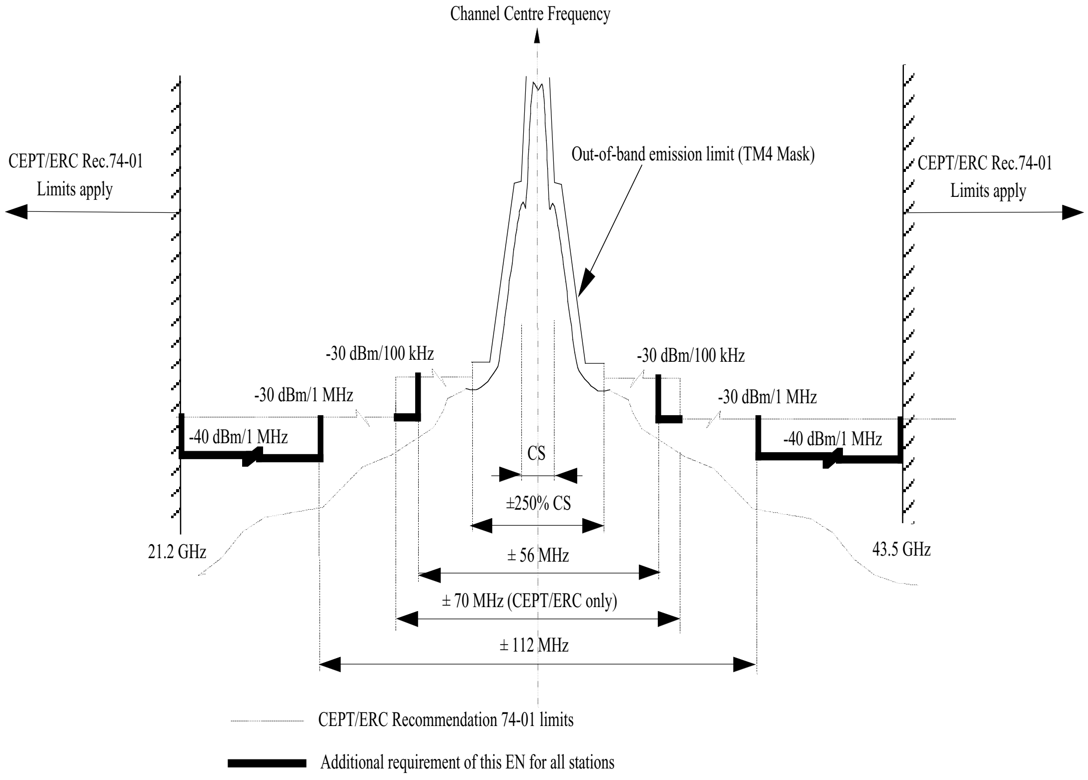
In regions where they apply, the limits of ETSI EN 301 390 (2003-11) should be followed.

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

According to 4.1.3 in ETSI EN 301 390 (2003-11), the following requirements should be used in Europe:

- For spurious emissions in the frequency range from 9 kHz to 21.2 GHz and above 43.5 GHz, CEPT/ERC Recommendation 74-01 (2002) [B1] applies.
- For spurious emissions falling in the range from 21.2 GHz to 43.5 GHz, the tighter limits shown in Figure 7 and Figure 8 apply to both base and SSs. In this frequency range, where the –40 dBm limit shown in Figure 7 and Figure 8 applies, allowance is given for no more than 10 discrete continuous wave spurious emissions that 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 (2002) [B1] are also shown.



Source: ETSI 390 EN 301-390 V1.1.1. © ETSI 2000. Further use, modification, and redistribution is strictly prohibited. ETSI standards are available from publication@etsi.fr and http://www.etsi.org/eds/eds.htm.

Figure 7—Systems for channel separation (CS) 1 < CS ≤ 10 MHz

5.5.2 Receiver design parameters

This subclause provides recommendations for the design of both SS and BS receivers, which are to be deployed in FBWA systems. The parameters for which recommendations are made are those that affect performance in the presence of interference from other FBWA systems.

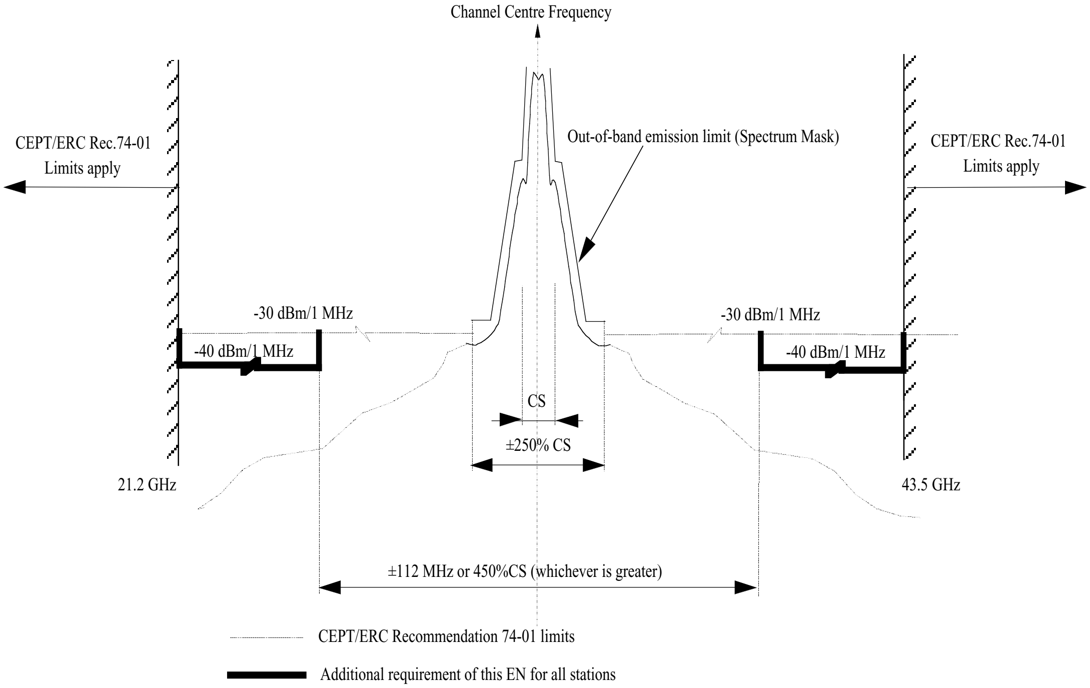


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Figure 8—Systems for CS > 10 MHz

5.5.2.1 CoCh 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 FBWA 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.

5.5.2.1.1 Base station (BS)

The BS receiver might be subjected to AdjCh interference and CoCh interference from other FBWA systems operating in close proximity to the reference system. Therefore, the BS receivers should be designed with proper selectivity and tolerance to interference.

5.5.2.1.2 Subscriber station (SS)

The SS receiver might be subjected to AdjCh interference and CoCh interference from other FBWA 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.

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

From the simulation results described in other subclauses of this recommended practice, 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 FBWA at 26 GHz as identified in 5.5.1.1. A 4-point quadrature amplitude modulation (4-QAM) system is assumed with an excess bandwidth of 15% and a receiver noise figure of 6 dB. Availability objectives of 99.995% for a bit error ratio (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 horizontally polarized transmission has been assumed.

For *I/N* = –6 dB, *C/I* = 19 dB, and the effective receiver threshold is impaired by approximately 1 dB so 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 9 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%.

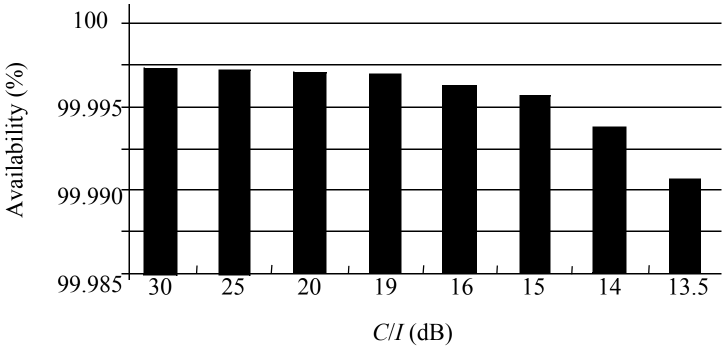

Figure 9—Availability versus *C/I* for a fixed cell radius for *R* = 3.6 km

Figure 10 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.

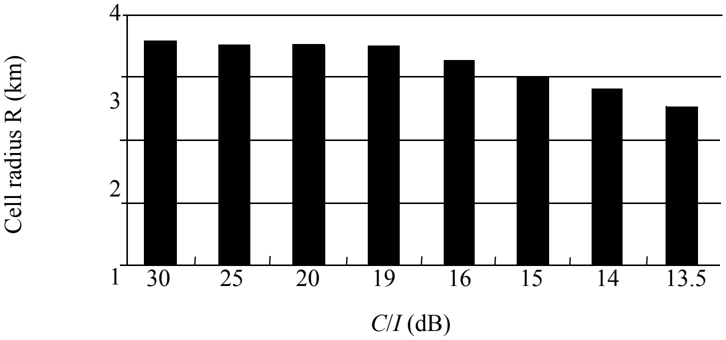

Figure 10—Radius versus *C/I* for a fixed availability of 99.995%

5.5.2.2 AdjCh 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 AdjCh carriers. The recommended numerical values below are based on the emission mask in 5.5.1.3, quadrature phase shift keying (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 AdjCh carrier interference, as defined by NFD, establishes the requirements and that interfering signals have not degraded the NFD. Thus, the tests in 5.5.2.2.1 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 ratio of desired carrier (*D*) to undesired carrier (*U*), *D/U*. The *D* emissions should correspond to the signal characteristics normally expected to be present at the victim receiver input port.

5.5.2.2.1 BS and SS *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 and undesired signals coupled to the input of the victim *D* receiver, set the input level of the desired signal so that it is 3 dB above the nominally specified BER performance threshold.

5.5.2.2.1.1 First AdjCh *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.

5.5.2.2.1.2 Second AdjCh *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 B.1.3).

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

5.6 Deployment and coordination

This subclause provides a recommended structure process to be used to coordinate deployment of FBWA systems in order to minimize interference problems.

NOTE—National regulation and/or international agreements may impose tighter limits than the following and 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.

5.6.1 CoCh/adjacent-area case

5.6.1.1 Methodology

Coordination is recommended between licensed service areas where both systems are operating CoCh, i.e., over the same FBWA 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.[5] The rationale for 60 km is given in 5.6.1.2. 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 in the following paragraph, two alternative coordination procedures are described in B.5 (based on a different *I/N*) and B.6 (based on a two-tier psfd approach).

FBWA operators should calculate the psfd at their own service area boundary, 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 5.6.1.2 for a rationale behind the psfd levels presented in this process. The limits here refer to an operator's own service boundary, because 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

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[5] In the 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).

service areas, a similar relaxation could be applied. However, in this case, caution is needed because both existing operators may have to reengineer their systems if service later begins in this intervening land mass.

Deployment of facilities that generate a psfd, averaged over any 1 MHz at their own service area boundary, less than or equal to that stated in Table 3, should not be subject to any coordination requirements.

Table 3—Maximum psfd limits

Frequency band (GHz)	**psfd dB[(W/m^2)/MHz]**
24, 26, 28	–114
38, 42	–111

5.6.1.2 Coordination trigger

As described in 5.6.1.1, 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.

The rationale for 60 km is based upon several considerations, including radio horizon calculations, propagation effects, and pfd levels. The last consideration is discussed in 5.6.3.

The radio horizon, defined as the maximum LOS distance between two radios, is defined (see Figure 11) as follows:

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

where

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

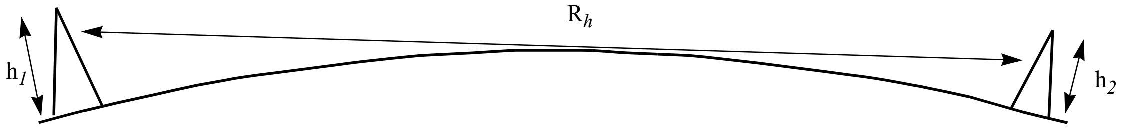


Figure 11—Geometry of radio horizon

Table 4 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 4—Horizon range for different radio heights above ground level (in km)

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 BSs, as these are typically located on relatively high buildings or infrastructures and hence have greater radio horizon distances than SSs. A typical height for a BS 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 BS equipment may be located on higher buildings, which would produce a greater radio horizon. However, these BSs tend to tilt their antennas downward. This effectively reduces the amount of power directed towards the adjacent BS and, therefore, reduces the interference. The following subclauses examine power levels in further detail.

5.6.2 Same-area/adjacent-frequency case

As stated in Recommendation 1-7 (see 5.2.7), 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 the size of the wider channel system. This recommended practice does not consider the case where an operator deploys multiple channel sizes within his or her allocation.

5.6.3 Use of psfd as a coexistence metric

This subclause addresses the maximum pfd that can be tolerated as a result of CoCh interference originating from an adjacent licensed operator. For the purposes of the recommendations in this recommended practice, the amount of interference generally considered acceptable or tolerable is a level that 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 B.2, a typical psfd calculation is shown at frequencies of 28 GHz and 38 GHz. The psfd limit can be applied in different ways that affect the probability of interference. Two examples are given in B.2 and B.7.

The 38 GHz band has been used extensively for individual PTP radio links for a number of years in many countries. More recently, the band has also been used to provide PTP links in support of FBWA systems. Thus, it is important that these PTP radio receivers be afforded an equal opportunity to coexist with PMP equipment in a shared frequency environment. Where there is significant deployment of PTP links as well as

PMP systems and protection of PMP systems is mandated, tighter psfd trigger levels may be appropriate [e.g., –125 dB(W/m^2) in any 1 MHz band at 38 GHz band is applied by some administrations to protect PTP links].

5.6.4 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 recommended practice to provide specifics.

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

5.7.1 Guidelines for geographical and frequency spacing between FBWA systems

This subclause indicates some of the models, simulations, and analysis used in the derivation of the recommendations described in 5.2 and the guidelines in 5.3. While a variety of tools can be used, it is suggested that the scenarios studied 5.7.1.2 be considered when coordination is required.

5.7.1.1 Summary

This subclause provides guidelines for geographical and frequency spacings of FBWA systems that would otherwise mutually interfere. The guidelines are not meant to replace the coordination process described in 5.6. 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.

5.7.1.2 Interference mechanisms

Various interference mechanisms can reduce the performance of FBWA 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 FBWA use, different types of systems may be deployed, some conforming to IEEE 802.16™ standards and some designed to other specifications. Therefore, a wide range of possibilities is considered in determining the likely interference levels and methods for reduction to acceptable levels.

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

- CoCh 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 interference will occur. Between any two systems, several interference mechanisms may be operating simultaneously (see 5.4). 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 as follows:

- Worst-case analysis
- Monte Carlo simulations
- Interference area (IA) method

These techniques are described in 5.7.1.3 through 5.7.1.5. 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. In Table 1 and Table 5 the values are shown for the results as guidelines for nominal geographical or frequency spacing.

5.7.1.3 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.

5.7.1.4 Monte Carlo 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 SSs 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 FBWA 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.

5.7.1.5 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 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 IA 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 IA 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 IA value can be calculated and is easily identified on the diagram. Figure B.6 (in B.3.4) provides an example.

5.7.1.6 Interference scenario occurrence probability (ISOP)

Although not used in this recommended practice, 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 CERT/ERC Report 099 (2002) [B3].

5.7.1.7 Simulations and calculations

Table 5 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 5—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, CoCh	Monte Carlo simulation	40 km BS-BS (different system)
BS to SS	FDD/TDD	Same area, AdjCh(s)	Monte Carlo simulation	1 guard channel (Note 2)
SS to BS	FDD/TDD	Same area, AdjCh	Monte Carlo simulation	1 guard channel (Note 2)
BS to SS	FDD/TDD	Same area, AdjCh	IA	1 guard channel = 0.5–2% IA (Note 2)
BS to BS	FDD/TDD	Same area, AdjCh	Monte Carlo simulation	1 guard channel (Note 2)
SS to SS	TDD	Same area, AdjCh	Monte Carlo simulation	1 guard channel (Note 2)
SS to SS	TDD	Adjacent area, CoCh	Monte Carlo simulation	Low probability if BS-BS > 35 km (different system)
SS to BS	FDD/TDD	Adjacent area, CoCh	IA	35 km BS-BS (different system)
BS to BS (multiple interferers)	FDD/TDD	Adjacent area, CoCh	Monte Carlo simulation	60 km (Note 3)
Mesh to PMP BS	FDD /TDD	Adjacent area, CoCh	Monte Carlo simulation	12 km BS to mesh edge
Mesh to PMP SS	FDD /TDD	Adjacent area, CoCh	Monte Carlo simulation	Low probability if mesh edge to BS > 12 km
Mesh to PMP BS	FDD/TDD	Same area, AdjCh	Monte Carlo simulation	1 guard channel (Note 4)

Table 5—Summary of the simulations and calculations *(continued)*

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)
Mesh to PMP SS	FDD/TDD	Same area, AdjCh	Monte Carlo simulation	1 guard channel (Note 4)

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

NOTES
1—While the target level of interference is generally referenced to a level that 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—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.
3—The results from the multiple BS interference simulation are based on an adverse terrain assumption and on the use of omnidirectional BS antennas. The victim BS is assumed to be at a high location, with clear LOS to all interfering BSs. Results taking account of terrain and building losses and sectored BS antennas are for future analysis.
4—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.

5.7.1.8 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 radiation pattern envelopes (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.

5.7.1.9 Results of the analysis

Simulations have been undertaken for many of the interference mechanisms described in 5.7.1.10 and 5.7.1.11. A summary of each method and its results is given in B.3.

5.7.1.10 CoCh case

5.7.1.10.1 BS-to-BS co-polar case with single and multiple interferers

This scenario only occurs where the victim BS receiver is CoCh 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 CoCh, 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 result.

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 FBWA 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.

5.7.1.10.2 SS-to-BS CoCh case

In this case, single and multiple SSs need to be considered. Depending on the system design, the number of SSs that 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.

5.7.1.10.3 SS-to-SS CoCh 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 CoCh 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 SS.

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

5.7.1.11 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.

5.7.1.11.1 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.

5.7.1.11.2 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 B.3.3 and B.3.13, 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 B.3.12, shows that the same one channel guard band is a good guideline for uncoordinated deployment.

5.7.1.11.3 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) rerouting to avoid the worst pointing directions of antennas. An analysis of this case can be found in B.3.5 for the PMP case and in B.3.12 and B.3.13 for the mesh-to-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.

5.8 Mitigation techniques

5.8.1 General

This subclause describes some of the mitigation techniques that could be employed in case of CoCh 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 are achieved.

5.8.2 Frequency band plans

By retaining spare frequencies for use only when interference is detected, some potential CoCh and AdjCh 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 BSs, primarily because BSs are typically located on high buildings or other structures and, therefore, tend to have good clear LOS with neighboring BSs. BSs typically operate over 360°, and BSs are always transmitting.

Harmonized BSs 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 SSs and victim BSs. 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.

5.8.3 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.

5.8.4 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 BS 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 BSs and victim SSs.

5.8.5 Co-siting of BSs

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 BS transmitters helps to facilitate coexistence.

5.8.6 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 are needed between the PTP site and any BS site. To provide the maximum decoupling, the best possible PTP antenna RPE performance is preferable.

5.8.7 Antennas

5.8.7.1 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 such as 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.

5.8.7.2 Orientation

In certain system deployments, sectorized antennas 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.

5.8.7.3 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.

5.8.7.4 Directivity

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

Another possible option is to place the BS 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 frontlobe-to-backlobe isolation of the BS antennas. This can exceed 30 dB, to accommodate QPSK modulation and 16-point QAM (16-QAM).

5.8.7.5 Antenna heights

In circumstances where adjacent licensed BSs are relatively close to each other, another possible technique to avoid interference is to place the BS antenna at lower heights to indirectly create LOS blockages to neighboring BSs. 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.

5.8.7.6 Future schemes

In the future, alternative schemes may be available. For example, 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.

5.8.7.7 Polarization

Cross-polarization can be effective in mitigating interference between adjacent systems. A typical cross-polarization isolation of 25 dB to 30 dB can be achieved with most antennas today. This is sufficient to counter CoCh interference for QPSK modulation and 16-QAM 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.

5.8.8 Blockage

Natural shielding, such as high 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.

5.8.9 Signal processing

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

5.8.10 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 intranetwork CoCh and AdjCh 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.

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

In order to reduce the internetwork contribution to ΣI, it is recommended that the effect of any FBWA network on any other coexisting BWA network should not degrade the receiver sensitivity of that FBWA network by more than 1 dB. This level triggers the coordination process described in 5.6.1.

5.8.11 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 BS of the system fault.

5.8.11.1 Fail-safe

It is recommended that the SS and BS 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.

6. Coexistence of FBWA systems with PTP links in 23.5 GHz – 43.5 GHz

This clause defines a set of consistent deployment recommendations that promote coexistence between FBWA systems and PTP systems that share the same band within the 23.5–43.5 GHz frequency range. Each scenario considers the case where one component is a single, individually planned, static PTP link or a system comprising multiple PTP links operating dynamically within a frequency block and where the other component is a FBWA system, which may be the victim or the interferer. The full details of the simulation work are contained in input documents referenced in Annex A.

6.1 Recommendations and guidelines

Recommendations 1-1, 1-2, 1-3, 1-8, 1-10, and 1-11, as provided in 5.2, apply to the current case. In addition, the recommendations in 6.1.1 through 6.1.6 also apply to this case.

6.1.1 Recommendation 2-1

No coordination is needed if a PTP station pointing towards a service area boundary is located greater than 80 km from either the service area boundary or the neighbor’s boundary (if known) in the direction of the link. Based on typical FBWA and PTP system equipment parameters and an allowance for potential LOS interference couplings, subsequent analyses indicate that a 80 km boundary distance is sufficient to preclude the need for coordination. At lesser distances, the requirement for coordination should be subject to a detailed examination of the specific transmission path details that may provide for interference link excess loss or blockage. This coordination criterion is viewed to be necessary and appropriate for both systems that conform to this recommended practice and systems that do not.

6.1.2 Recommendation 2-2

This recommendation applies to CoCh cases only. Recommendation 1-2 introduced the concept of using psfd 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. As a guide, the following values may be considered: Coordination trigger values of –114 dB(W/m^2) in any 1 MHz band (24 GHz, 26 GHz, and 28 GHz bands) and –111 dB(W/m^2) in any 1 MHz band (38 GHz and 42 GHz bands) as detailed in Table 3 can still be considered valid. To some extent, the choice depends on the importance an administration may place on protecting PTP systems, balanced against imposing additional constraints on MP system deployment. As an example, a coordination trigger value of –125 dB(W/m^2) in any 1 MHz band to protect PTP links in the 38 GHz band is employed by one administration in the initiative procedure described in Annex D.

The evaluation point for the trigger exceedance may be at the victim operator’s licensed area boundary, at 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. 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 interference potential.

In common with Recommendation 1-6, these triggers 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.

6.1.3 Recommendation 2-3

For same-area/AdjCh interference cases, analyses and simulations indicate that operation of individually planned static PTP links within the same geographical region in adjacent frequencies will always have considerable constraints on antenna pointing, if damaging interference is to be avoided. Although careful worst-case coordination is always recommended, at least a single guard channel should be considered, in order to reduce the coordination issues to manageable avoidance of main beam couplings between PTP stations and PMP BS or SS.

However, where multiple PTP links operate dynamically within a frequency block assignment, further analysis suggests that frequency separation alone, equivalent to two channels of operation, can be recommended and is sufficient to facilitate adequate coexistence.

The ability to coexist depends upon the amount of guard frequency, distance separation, physical blockage, OOB emission levels, and antenna decoupling and, in the case of links operating dynamically, is linked to the probability of interference in given deployment scenarios.

6.1.4 Recommendation 2-4

When assigning both PMP frequency blocks and channels or blocks for individually planned static PTP links, in the same frequency band, it will be useful to maximize the frequency separation possibilities and begin assignments from opposite ends of the band.

6.1.5 Recommendation 2-5

Keep deployment height to the minimum necessary for the type of service and application. Local features can provide useful obstacles to help mitigate against interference into adjacent operator installations.

6.1.6 Recommendation 2-6

In order to improve NFD values at the edges of the assigned frequency block, it is recommended to start populating the block from the middle and expanding towards the ends. Where different channel sizes are used within a block, it is recommended to assign the smaller bandwidth channels adjacent to the edges of the block.

6.2 Suggested guidelines for geographical and frequency spacing

This subclause summarizes the models, simulations, and analyses used in Clause 6 and provides guidelines for the most severe of the mechanisms identified. The complete set of interference mechanisms is described in C.2.

Guidelines for geographical and frequency spacing between FBWA systems and PTP links that would otherwise mutually interfere are given in 6.2 for each of a number of interfering mechanisms. The two main deployment scenarios are as follows:

- CoCh 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 6. The information is intended to provide a first step in planning the deployment of systems.

Table 6—Dominant interference mechanisms between FBWA and PTP systems

Dominant interference path[a]	Scenario	Spacing at which interference is below target level (generally 6 dB below receiver noise floor)
PMP SS to PTP link station (If the SS antennas are low, the BS case may become dominant, in which case over-the-horizon spacing is still required.)	Adjacent area, same channel	Over the horizon (typically > 60 km) or combination of large antenna pointing offset and geographical spacing
PTP link station to PMP SS (If the SS antennas are low, the BS case may become dominant.)	Adjacent area, same channel	50–80 km for typical PTP link parameters. If the BS case becomes dominant, lower spacing may be feasible.
PMP BS to PTP link station	Same area, AdjCh	Single guard channel[b] plus restrictions on pointing directions
PTP link station to PMP BS	Same area, AdjCh	Single guard channel[b] plus restrictions on pointing directions
PMP BS to multiple PTP link system	Adjacent area, same channel	80 km for typical system parameters
Multiple PTP link system to PMP BS	Adjacent area, same channel	20–24 km for typical system parameters
PMP BS to multiple PTP link system	Same area, AdjCh	2 guard channels
Multiple PTP link system to PMP BS	Same area, AdjCh	1 guard channel

[a] The dominant interference path is that path that establishes the largest geographical or frequency spacing in order to meet the specified interference target.

[b] The guard channel size assumes that the interferer and victim use the same channel size. If they are not equal, then the guard channel should be the wider of the channel sizes of the two systems.

6.3 System overview (interferer and victim systems)

In all cases, a FBWA system is present and may be the victim or interferer. The other system is a PTP link or an arrangement of several PTP links. There are two main licensing scenarios for the PTP link component, each of which is described below.

FBWA systems are described in Clause 5. They are generally of PMP architecture, or sometimes MP-MP. Although information on BS locations may be readily available, SSs are added and removed regularly and information on their locations is not usually available to third parties.

PTP links are simple, generally LOS, and direct connections by radio, using narrow beam antennas. Once installed, they usually have a long lifetime without any changes being made to operating frequencies or other characteristics. They are used for backhaul, intercell links and for transmission of telecommunications and entertainment services between fixed points.

Occasionally, systems may comprise a set of PTP links, planned and deployed by an operator from a frequency block assignment. They may be used for various applications. In this case, the links may be less permanent than many of the individual links described above. The configuration may vary as the operator's client base evolves.

6.3.1 Interference scenario 1: multiple PTP links in a frequency block

In some territories, PTP links may share frequency blocks with MP systems. In this scenario, the links are permitted to operate within a frequency block, and the operator assigns specific frequencies. The system operator decides the link frequencies within the block, determines the antenna characteristics and manages coexistence issues. The regulatory authority does not have responsibility for resolving interference issues, except possibly at block boundaries.

Because the PTP link arrangements can change over time, an analysis of interference is best carried out using Monte Carlo simulation techniques, to provide general guidelines for frequency and geographical spacing. The guidelines should be chosen so that the probability of interference above some chosen threshold is acceptably low.

6.3.2 Interference scenario 2: individually licensed links

In some territories, PTP links share frequency bands with MP systems, and the links operate in separate frequency blocks and are often individually licensed. In this scenario, the national regulator assigns the link frequencies, determines the antenna characteristics, and manages coexistence issues. The operator of the PTP link is not free to alter link frequencies or other characteristics without agreement of the regulator. The links are often given a protected status over the other services sharing the band, so that the onus is on the operator of the FBWA system to avoid generating unacceptable interference.

Because links are generally protected in this scenario, a worst-case analysis rather than a statistical approach is appropriate. The guidelines should be set to avoid all cases of unacceptable interference to (but not necessarily from) the PTP link.

6.3.3 System parameters assumed in the simulations

Table 7 and Table 8 giving parameters for PTP systems were developed as a starting point for simulations and other calculations used in the interference studies.

Table 7—Characteristics of system with multiple PTP links

Characteristic (PTP systems)	Examples
Layout of system(s) including diagrams	Quasi-random layout of links Consider multiple star/hub configurations
Link lengths	50–5000 m at 25 GHz 50–3000 m at 38 GHz
Density of terminal stations	Up to 5 per km^2
Distribution of terminal stations in relation to link length	Uniform (all link lengths have same probability)
Frequency of operation (for each variant to be studied)	Circa 25 GHz, circa 38 GHz
Duplex method	FDD
Access method	N/A
Receiver parameters	
Channel bandwidth	12.5, 14, 25, 28, 50, 56 MHz
Filter response	Root Nyquist, roll-off factor = 0.25
Noise floor	6 dB noise figure at 25 GHz, 9 dB at 38 GHz
Acceptable level for CoCh interference	$I/N = -6$ dB (aggregate of all interferers)
Transmitter parameters	

Table 7—Characteristics of system with multiple PTP links *(continued)*

Characteristic (PTP systems)	Examples
Channel bandwidth	12.5, 14, 25, 28, 50, 56 MHz
Emission mask	See ETSI EN 301 213-1 (2002-02) [B8]
Maximum mean power (at antenna port)	1 W
Typical power	To meet link availability objectives of 99.99%
Use of ATPC, steps and range	Uplink and downlink, 2 dB steps, 40 dB range
NFD	See CEPT/ERC Report 099 (2002) [B3]
Antenna characteristics (station at point of connection to backhaul or core network)	Composite RPE 1 ft antenna as in 6.3.4.2. Gain 40–42 dBi.
Antenna characteristics (SS)	Composite RPE 1 ft antenna as in 6.3.4.2. Gain 40–42 dBi.
Antenna characteristics (RS)	Same as other antennas
Backhaul links	In-band, separate assignments

Table 8—Characteristics of PTP link [a]

Characteristic (PTP systems)	Examples
Layout of system(s) including diagrams	Individual, planned link, coordinated by regulatory body
Link lengths	50–5000 m at 25 GHz 50–3000 m at 38 GHz
Density of terminal stations	N/A
Distribution of terminal stations in relation to link length	N/A
Frequency of operation (for each variant to be studied)	25 GHz, 38 GHz
Duplex method	FDD
Access method	N/A
Receiver parameters	
Channel bandwidth	12.5, 14, 25, 28, 50, 56 MHz
Filter response	Root Nyquist, roll-off factor = 0.25
Noise floor	6 dB noise figure at 25 GHz, 9 dB at 38 GHz
Acceptable level for CoCh interference	I/N = –6 dB (aggregate of all interferers)
Transmitter parameters	
Channel bandwidth	12.5, 14, 25, 28, 50, 56 MHz
Emission mask	See ETSI EN 301 213-1 (2002-02) [B8]
Maximum mean power (at antenna port)	1 W
Typical power	To achieve link budget

Table 8—Characteristics of PTP link [a] *(continued)*

Characteristic (PTP systems)	Examples
Use of ATPC, steps and range	Uplink and downlink, 2 dB steps, 40 dB range
NFD	See CEPT/ERC Report 099 (2002) [B3]
Antenna characteristics (station at point of connection to backhaul or core network)	Composite RPE 1 ft and 2 ft antenna(s) as in 6.3.4.2 Gain = 40–42 dBi
Antenna characteristics (SS)	Composite RPE 1 ft and 2 ft antenna(s) as in 6.3.4.2 Gain = 40–42 dBi
Antenna characteristics (RS)	N/A
Backhaul links	In-band, separate assignments

[a] Where assignments for PTP systems are made in the same frequency bands as fixed wireless access systems.

6.3.4 Antenna parameters

For each interference scenario, two types of antenna are involved. One type is associated with a FBWA system (which may be the interfering or victim system), and the other type is associated with a PTP link or set of PTP links. Antennas for these two types of systems have different characteristics, as described in 6.3.4.1 and 6.3.4.2.

6.3.4.1 Typical PTP link antenna characteristics

Research into typical antennas for links operating around 25 GHz and around 38 GHz has been used to compile a set of composite antenna characteristics for PTP links. While these are not intended as a basis for antenna design, they are considered to be adequate to meet reasonable interference objectives and practically feasible (i.e., it could be expected that a number of manufacturers could supply antennas meeting these criteria).

These composite antenna RPEs have, therefore, been used for the PTP link component of the analyses in the simulation work carried out in Clause 6 of this recommended practice. Each antenna is specified by creating a RPE for each co-polarization and cross-polarization. The RPE is a mask created with a series of straight lines that represents the sidelobes of the antenna in decibels relative to the main beam at all azimuth angles for either a co-polarized or cross-polarized signal.

Using these generic composite envelopes in interference studies ensures that antennas are readily available from more than one manufacturer. The results of the simulations may indicate that an antenna with a better RPE is needed. If so, better antennas are available, but may be more costly.

6.3.4.2 Construction of a composite RPE

The tabular data for each antenna RPE was obtained from each manufacturer’s published RPE. To construct the generic RPE, the RPE of each manufacturer was plotted on the same axes. A composite mask was then drawn over the worst of the set of curves. This was done for two common sizes of HP antennas in each band. Figure 12 illustrates the composite co-polarized mask for a 38 GHz 1 ft diameter antenna using data from four different manufacturers. The same procedure is also applied to the cross-polarized RPE shown in Figure 13.

The same procedure was applied to 2 ft diameter 38 GHz models using data from four manufacturers. For the 1 ft diameter and 2 ft diameter 26 GHz models, the data of three manufacturers were used for each composite RPE. The actual composite plots for these six models are not shown. However, the composite RPE of each is shown later in this recommended practice compared to selected standards. Tables of breakpoints for each composite RPE are shown below each plot. The tables associated with the standards have been omitted in this recommended practice.

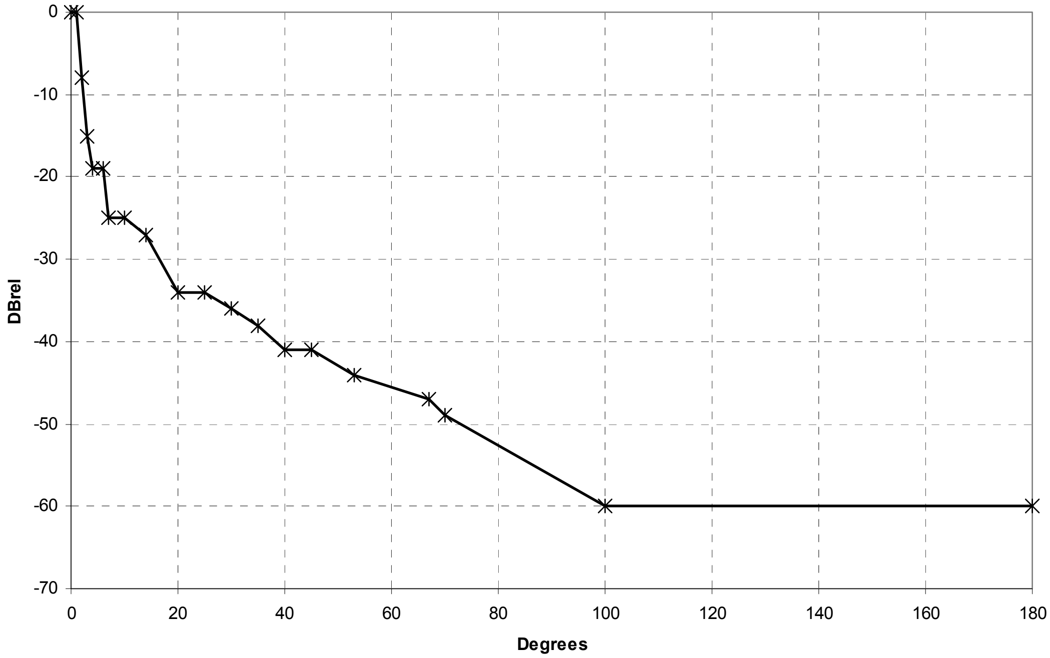


Figure 12—Composite co-polarized RPE for 1 ft HP 38 GHz antenna

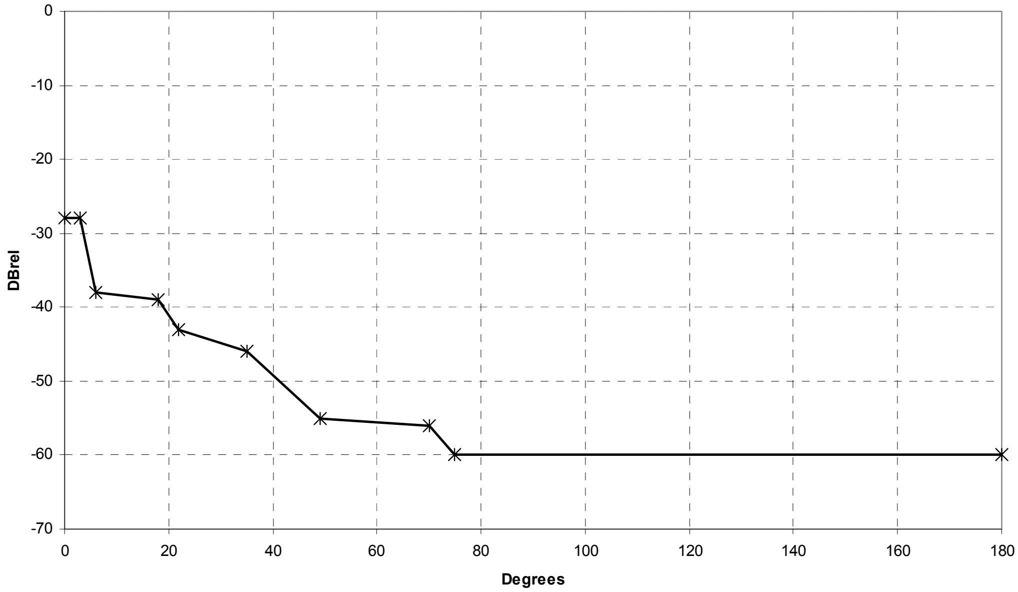


Figure 13—Composite cross-polarized RPE for 1 ft HP 38 GHz antenna

The composite RPE was derived from the worst case limits of a series of commercially available antennas. In order to improve clarity, details of the many individual antenna RPEs have not been shown. These can be found in Whiting [B69].

6.3.5 Comparison of the composite RPE to standards

Each composite RPE was compared to a selected number of standards that included ETSI EN 300 833 (2002-07) [B59] (ETSI Class 2), FCC Standard A, and other typical subscriber antennas, referred to in the figures as "IEEE Class 2" and "IEEE Class 3." Figure 14 through Figure 21 (with Table 9 through Table 16) illustrate those comparisons. In a few cases the composite RPE was slightly worse than ETSI Class 2. In those cases a modified composite RPE was generated that satisfies the ETSI specification. The rationale for those modifications is that PTP links generally require antennas that at least satisfy ETSI Class 2. The modifications are so slight that they do not significantly affect the availability of antennas that can meet the modified composite RPE.

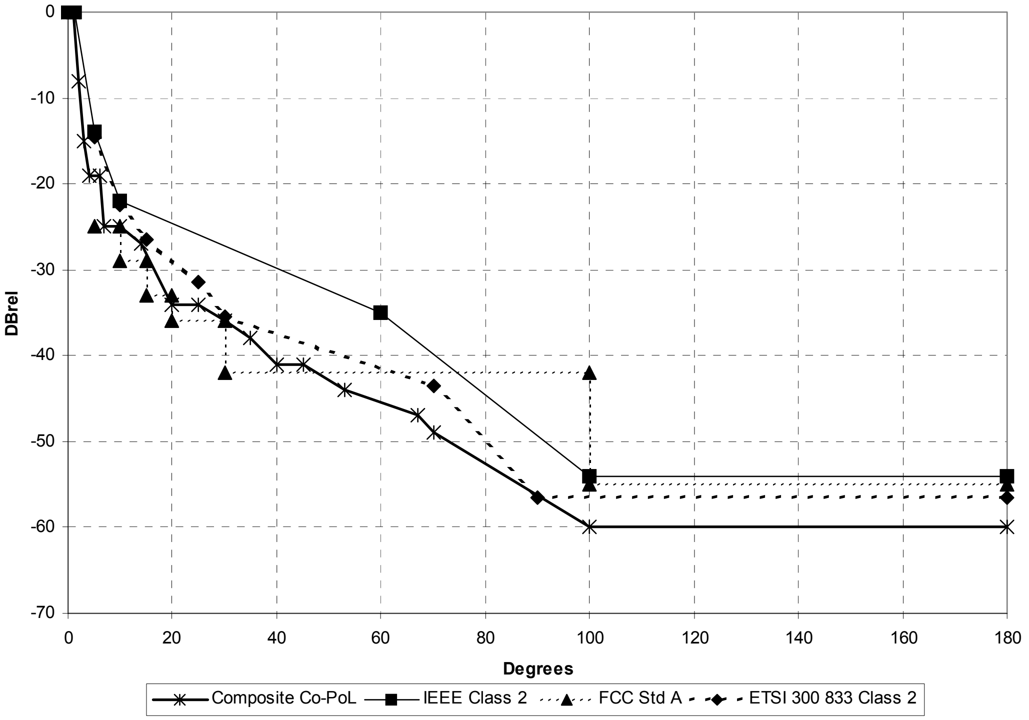


Figure 14—Comparison of co-polarized composite of HP 1 ft 38 GHz antennas

Table 9—Breakpoints of co-polarized composite of HP 1 ft 38 GHz antennas

Angle (°)	dB_{rel}	Angle (°)	dB_{rel}	Angle (°)	dB_{rel}	Angle (°)	dB_{rel}
0	0	6	–19	25	–34	53	–44
1	0	7	–25	30	–36	67	–47
2	–8	10	–25	35	–38	70	–49

Table 9—Breakpoints of co-polarized composite of HP 1 ft 38 GHz antennas

Angle (°)	dB$_{rel}$	Angle (°)	dB$_{rel}$	Angle (°)	dB$_{rel}$	Angle (°)	dB$_{rel}$
3	–15	14	–27	40	–41	100	–60
4	–19	20	–34	45	–41	180	–60

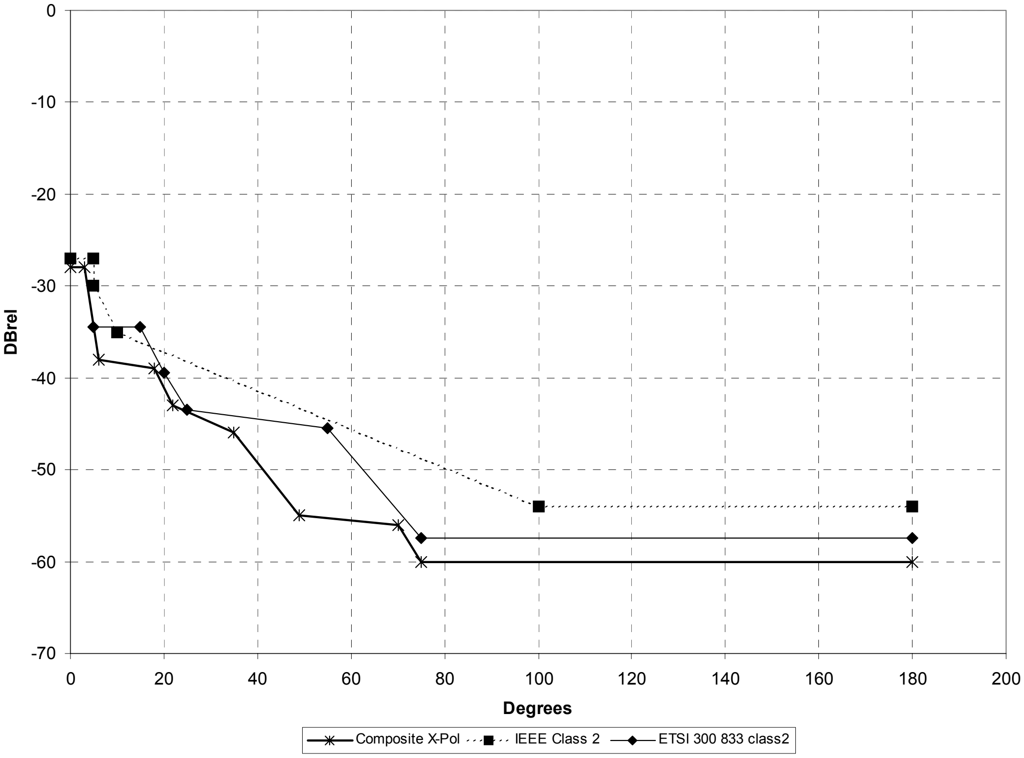


Figure 15—Comparison of cross-polarized composite of HP 1 ft 38 GHz antennas

Table 10—Breakpoints of cross-polarized composite of HP 1 ft 38 GHz antennas

Angle (°)	0	3	6	18	22	35	49	70	75	180
dB$_{rel}$	–28	–28	–38	–39	–43	–46	–55	–56	–60	–60

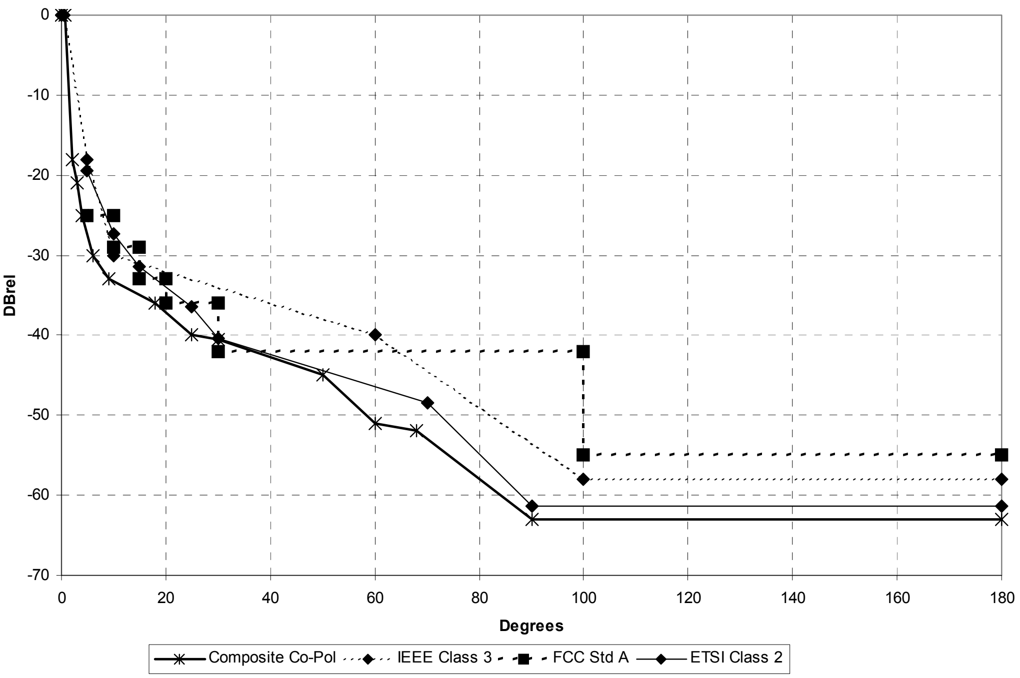


Figure 16—Comparison of co-polarized composite of HP 2 ft 38 GHz antennas

Table 11—Breakpoints of co-polarized composite of HP 2 ft 38 GHz antennas

Angle (°)	0	0.7	2	3	4	6	9	18	25	30	50	60	68	90	180
dB_{rel}	0	0	–18	–21	–25	–30	–33	–36	–40	–40.5	–45	–51	–52	–63	–63

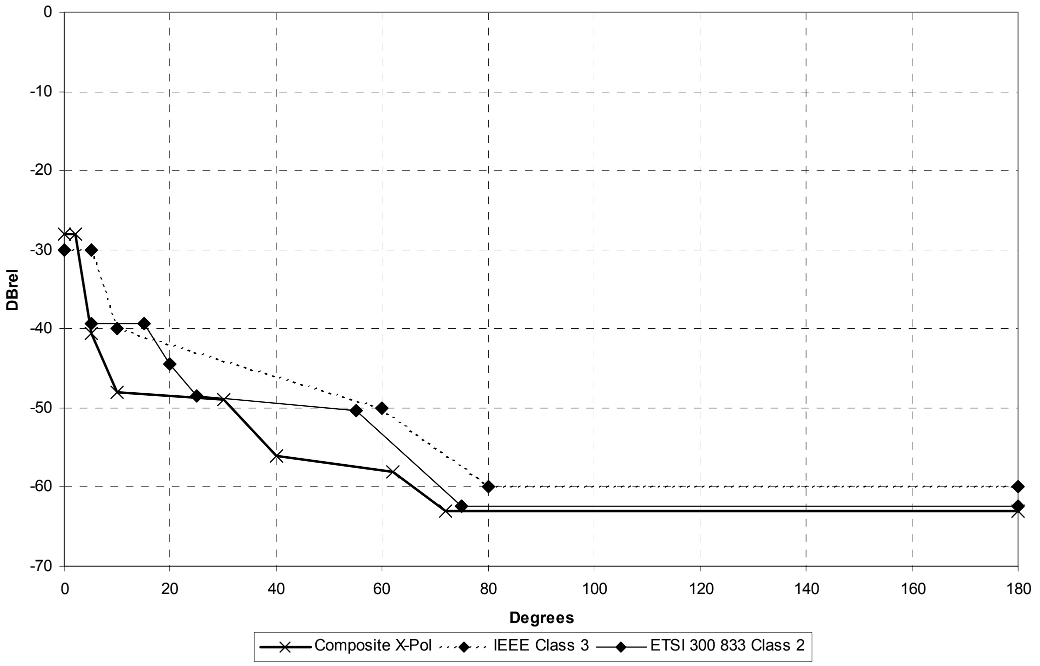


Figure 17—Comparison of cross-polarized composite of HP 2 ft 38 GHz antennas

Table 12—Breakpoints of cross-polarized composite of HP 2 ft 38 GHz antennas

Angle (°)	0	2	5	10	30	40	62	72	180
dB$_{rel}$	–28	–28	–40.5	–48	–49	–56	–58	–63	–63

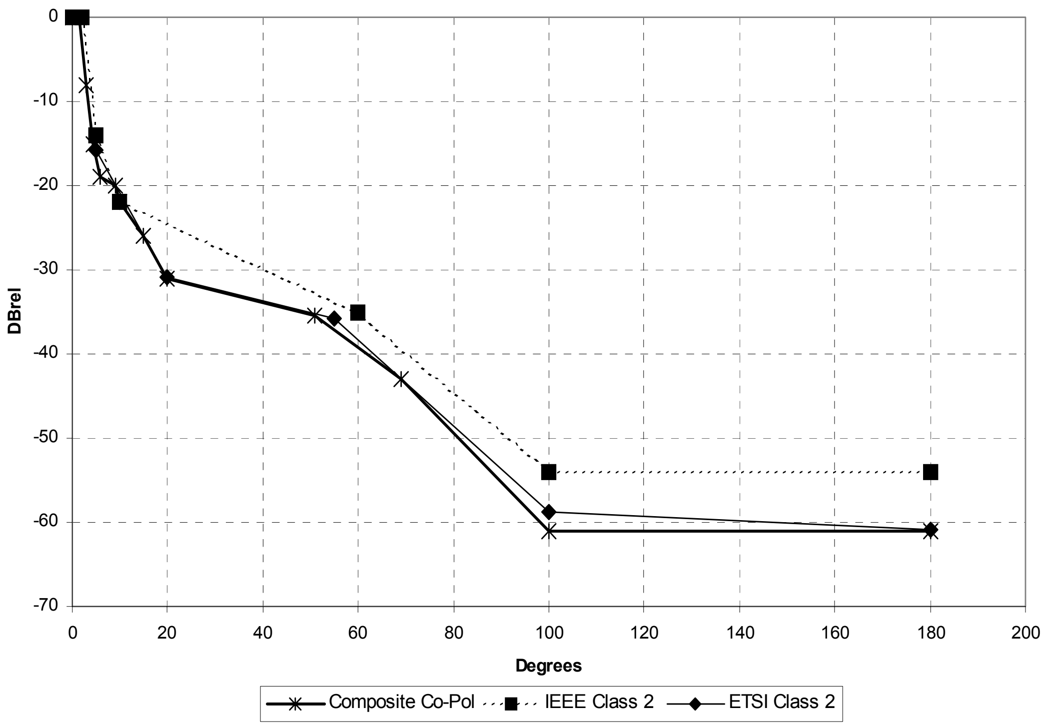


Figure 18—Comparison of co-polarized composite of HP 1 ft 25 GHz antennas

Table 13—Breakpoints of co-polarized composite of HP 1 ft 25 GHz antennas

Angle (°)	0	1.5	3	4.5	5.8	9	10	15	20	51	69	100	180
dB$_{rel}$	0	0	–8	–15	–19	–20	–22	–26	–31	–35.5	–43	–61	–61

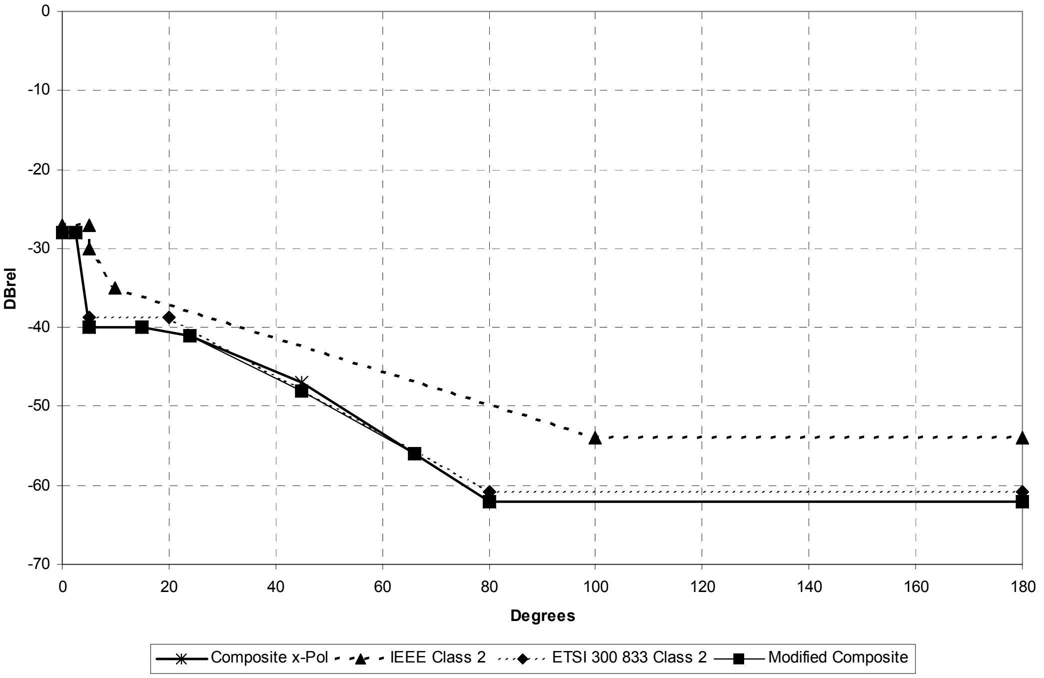


Figure 19—Comparison of cross-polarized composite of HP 1 ft 25 GHz antennas

Table 14—Breakpoints of cross-polarized composite of HP 1 ft 25 GHz antennas

Angle (°)	0	2.5	5	15	24	45	66	80	180
dB$_{rel}$	–28	–28	–40	–40	–41	–48	–56	–62	–62

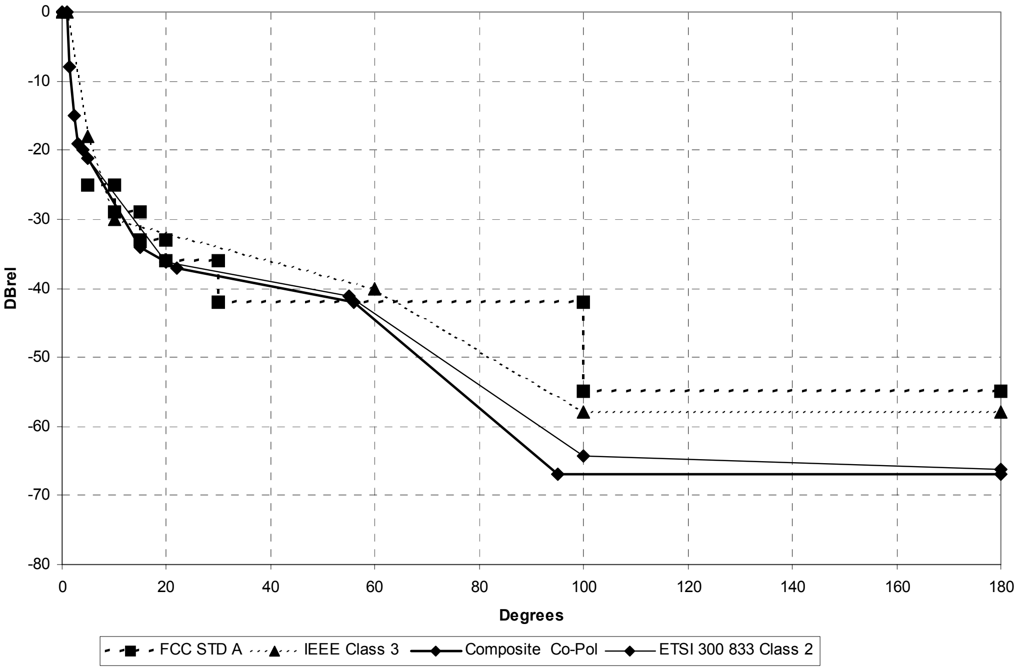


Figure 20—Comparison of co-polarized composite of HP 2 ft 25 GHz antennas

Table 15—Breakpoints of co-polarized composite of HP 2 ft 25 GHz antennas

Angle (°)	0	1	1.5	2.25	3	4	15	22	56	95	180
dB_{rel}	0	0	–8	–15	–19	–20	–34	–37	–42	–67	–67

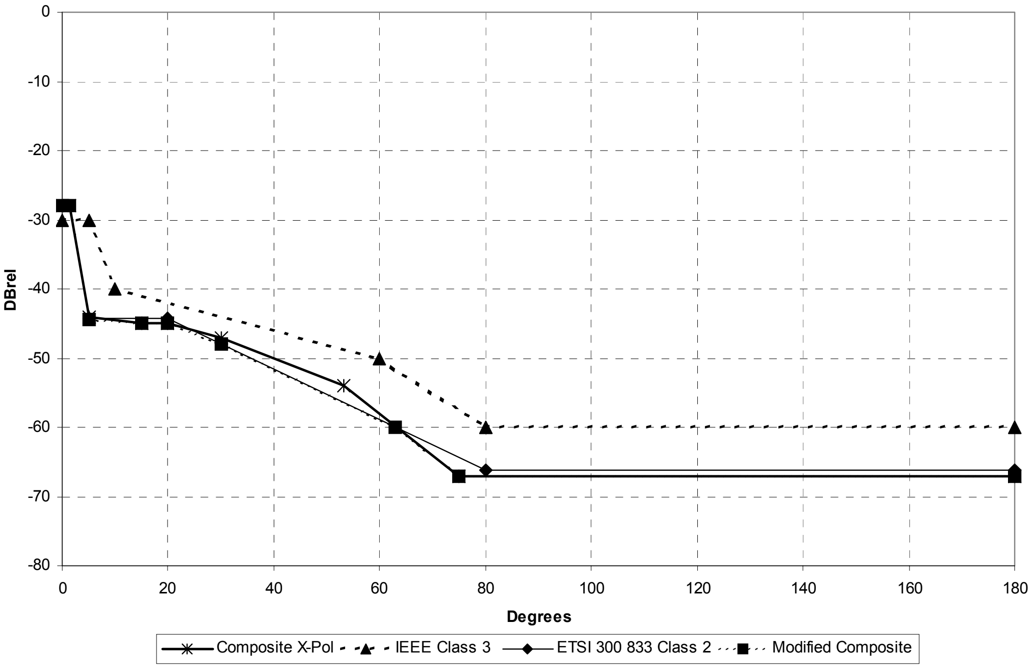


Figure 21—Comparison of cross-polarized composite of HP 2 ft 25 GHz antennas

Table 16—Breakpoints of cross-polarized composite of HP 2 ft 25 GHz antennas

Angle (°)	0	1.5	5	15	20	30	63	75	180
dB_{rel}	–28	–28	–44.5	–45	–45	–48	–60	–67	–67

6.4 Interference scenarios

Interference can be classified into two broad categories:

- CoCh interference
- Out-of-channel interference

Figure 2 (in 4.2.1) illustrates the power spectrum of the desired signal and CoCh interference in a simplified example. Note that the channel bandwidth of the CoCh interferer may be wider or narrower than the desired signal. In the case of a wider CoCh interferer (as shown), only a portion of its power will fall within the receiver filter bandwidth. In this case, the interference can be estimated by calculating the power arriving at the Rx antenna and then multiplying by a factor equal to the ratio of the filter's bandwidth to the interferer's bandwidth.

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 CoCh to the desired signal; i.e., within the receiver filter's passband. This can be treated as CoCh interference. It cannot be removed at the receiver; its level is determined at the interfering transmitter. By characterizing the psd 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 CoCh 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 CoCh 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 CoCh 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. In order to calculate the out-of-channel interference it is required to know both the interferer spectrum mask, $G(f)$, and the receiver blocking characteristics, $H(f)$. If the interferer's central frequency is separated by Δf from the receiver's, the total interference is a function of the NFD and the other losses and gains in the transmission path. NFD can be calculated from Equation (3).

$$\mathrm{NFD}(\Delta f) = \int G(f)H(f+\Delta f)df \tag{3}$$

6.4.1 Acceptable level of interference

The acceptable level of interference is –144 dBW in 1 MHz (i.e., 6 dB below the receiver thermal noise), per 4.2.2.

6.4.2 Interference paths

In this subclause, interference to and from PTP links and link systems (systems comprising a number of PTP links) is considered. The interference between two separate FBWA systems is covered by Clause 5 and is not considered further here.

6.4.2.1 Victim BS

Where the victim receiver is a FBWA BS, with a typical sectoral-coverage antenna, interference can arise from a single PTP link station or from multiple such stations in an area. In the worst case, the desired signal travels through localized rain cell and is received at minimum signal strength. Thus, interference levels close to the thermal noise floor are significant. The analyses for single interferers and multiple interferers require different methods.

6.4.2.2 Victim SS

Where the victim receiver is a FBWA SS, with a typical narrow beam antenna, interference can arise from a PTP link station or a number of PTP link stations in an area. In either case, the interference path is between two stations with narrow beam antennas, so that normally only one interferer will be significant due to the low probability of alignment. Where rain fading occurs, it will almost certainly affect the wanted and interfering paths at the same time.

6.4.2.3 Victim PTP link

Where the victim receiver is a fixed PTP link station, the interferer may be a FBWA BS or SS. The probability of interference is higher when the interferer is a BS. In the case of a victim station forming part of a system with multiple PTP links, the interference scenario is similar to that for an individual PTP link station, but the acceptable level may be different. This occurs because the individual links considered in this scenario are assumed to have a protected status (where interference is managed by the regulatory body) while the multilink systems are assumed to be within an operator's block assignment, with specific frequencies determined by the operator from within the available block.

6.5 Equipment design parameters

Equipment design parameters appropriate to the FBWA systems considered in this clause are provided in Clause 5.

For the PTP system or the system with multiple PTP links, the typical parameters in Table 7 and Table 8 (see 6.3.3) have been assumed.

6.6 Deployment and coordination between PMP and PTP systems

6.6.1 CoCh/adjacent-area case

The basis for coexistence in this scenario where CoCh PTP links (either individually planned static links or multiple PTP links within a frequency block that may be operating dynamically) are to be deployed in an adjacent license area is substantially the same as that described for PMP systems detailed in 5.6.1.

However, it is recommended that coordination is carried out when distances between service area boundaries is less than 80 km. This accounts for the possibility of PTP stations having different characteristics from PMP stations and being located at greater heights than conventional PMP stations.

FBWA operators should calculate the psfd at their own service area boundary as detailed in Clause 5 and evaluate against the appropriate coordination trigger level.

Generally, deployment of facilities that generate a psfd, averaged over any 1 MHz at their own service area boundary, less than or equal to that stated in Table 3 (see 5.6.1.1), should not be subject to any coordination requirements.

However, there may be more stringent national criteria applied by specific administrations that should take precedence.

6.6.2 Same-area/adjacent-frequency case with individually planned static links

In order to evaluate the coexistence scenarios associated with PTP and PMP systems operating in the same area and in adjacent frequency blocks, reference was made to ETSI TR 101 853 (2000-10) [B16]. This report derives expressions that can be used to evaluate the coexistence potential for four possible interferer and victim system scenarios classified in the report as:

- Class B1 – PMP BS to PTP station
- Class B2 – PTP station to PMP BS
- Class B3 – PMP SS to PTP station
- Class B4 – PTP station to PMP SS

For Class B1 and Class B2 involving BSs, expressions are developed that can be used to calculate the minimum separation distance required between the PTP station and the PMP BS in order to meet a target minimum C/I ratio. For Class B3 and Class B4, expressions are developed that calculate the C/I ratio specific to decoupling angles between the SS and the PTP station. See Equations 28, 32, 37 and 40 in section 7 of ETSI TR 101 853 (2000-10) [B16].

6.6.3 Example calculations

The expressions developed in the ETSI technical report were used to carry out worst-case coexistence calculations between a PMP system operating in one frequency block adjacent to another frequency block dedicated to individually planned static PTP links. As far as possible, parameter values shown in 6.3 were used. Where suitable parameters were not available, reference was made to appropriate ETSI standards, i.e., ETSI EN 301 215-1 (2001-08) [B11], ETSI EN 300 431 (2002-07) [B58], and to Lewis [B60].

The calculation results are dependant on a large variety of possible parameter values. Definition of typical values is impractical since these will be different for any given scenario. Factors like PTP link length, planned availability, and PMP cell size, to name a few, can impact the parameter values chosen.

6.6.3.1 Class B1 and Class B2

Table 17 shows examples of minimum separation distance (D_{min}) between a PTP station and a PMP BS when the PTP station is the victim (Class B1). The calculated distances are in kilometers and given for a range of NFD values corresponding to frequency offset between the two systems and PTP to BS pointing angle offset. An indication of appropriate NFD columns is shown for CoCh (although not the issue here) and for first and second AdjChs representing the case where no guard channel is inserted between the system operating frequencies and where a single guard channel is inserted**.**

Table 17—Class B1, sample PMP-BS–to–PTP separation distances (km)

Angle (°)	**NFD (dB)**										
	0	**10**	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**70**
0.0	14455.3	460.2	145.5	81,8	46.0	25.9	14.6	8.2	4.6	2.6	0.5
1.5	14455.3	460.2	145.5	81,8	46.0	25.9	14.6	8.2	4.6	2.6	0.5
2.0	1070.5	338.5	107.1	60.2	33.9	19.0	10.7	6.0	3.4	1.9	0.3
2.5	787.5	249.0	78.8	44.3	24.9	14.0	7.9	4.4	2.5	1.4	0.2
3.0	579.3	183.2	57.9	32.6	18.3	10.3	5.8	3.3	1.8	1.0	< 0.2
4.5	258.8	81.8	25.9	14.6	8.2	4.6	2.6	1.5	0.8	0.5	< 0.2
5.8	163.3	51.6	16.3	9.2	5.2	2.9	1.6	0.9	0.5	0.3	< 0.2
7.4	154.1	48.7	15.4	8.7	4.9	2.7	1.5	0.9	0.5	0.3	< 0.2
9.0	145.5	46.0	14.6	8.2	4.6	2.6	1.5	0.8	0.5	0.3	< 0.2
9.3	134.8	42.6	13.5	7.6	4.3	2.4	1.3	0.8	0.4	0.2	< 0.2
9.7	124.8	39.5	12.5	7	3.9	2.2	1.2	0.7	0.4	0.2	< 0.2
10.0	115.6	36.6	11.6	6.5	3.7	2.1	1.2	0.7	0.4	0.2	< 0.2
11.0	105.4	33.3	10.5	5.9	3.3	1.9	1.1	0.6	0.3	< 0.2	< 0.2
12.0	96.1	30.4	9.6	5.4	3.0	1.7	1.0	0.5	0.3	< 0.2	< 0.2
13.0	87.7	27.7	8.8	4.9	2.8	1.6	0.9	0.5	0.3	< 0.2	< 0.2
14.0	80.0	25.3	8.0	4.5	2.5	1.4	0.8	0.4	0.3	< 0.2	< 0.2
15.0	72.9	23.1	7.3	4.1	2.3	1.3	0.7	0.4	0.2	< 0.2	< 0.2
16.0	65.5	20.6	6.5	3.7	2.1	1.2	0.7	0.4	0.2	< 0.2	< 0.2
17.0	57.9	18.3	5.8	3.3	1.8	1.0	0.6	0.3	0.2	< 0.2	< 0.2
18.0	51.6	16.3	5.2	2.9	1.6	0.9	0.5	0.3	< 0.2	< 0.2	< 0.2
19.0	46.0	14.6	4.6	2.6	1.5	0.8	0.5	0.3	< 0.2	< 0.2	< 0.2
20.0	41.0	13.0	4.1	2.3	1.3	0.7	0.4	0.2	< 0.2	< 0.2	< 0.2

For Class B2, the separation distance calculations gave lower values than for the equivalent B1 cases, leading to the conclusion that the Class B1 scenario is dominant when considering interference between a PTP station and a PMP BS.

The results indicate that even a single guard channel between the systems is insufficient to allow fully uncoordinated deployment. Separation distances of several kilometers are needed if boresight alignment occurs.

It is interesting also to consider the impact of these results within a grid of BSs as depicted in the Figure 22. In Figure 22 for illustrative purposes, the PTP station is operating in the AdjCh to the BSs. (Of course, a realistic frequency reuse plan may preclude all BS operating on the same frequency.) Examination of Table 17 shows that in the AdjCh and at a distance of 5 km a pointing angle offset of 13° is required. This leads to the range of PTP system pointing angles illustrated in Figure 22 (for one quadrant only) that could be possible based on the assumed parameter values for this calculation.

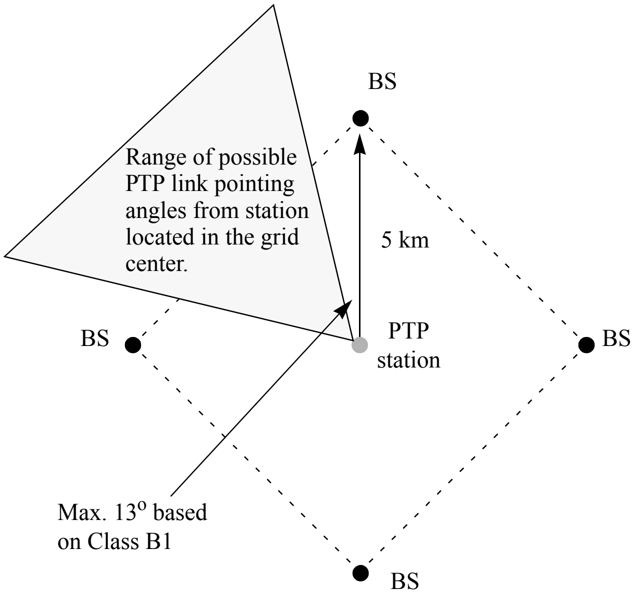


Figure 22—One interpretation of Table 17 results for no guard channel

Alternatively, the PTP station could be operated closer to the BS with a greater constraint on the pointing angle. For example, if the offset is 45°, then the PTP link could be as close as 1.5 km from the BS.

However, there could be other adjacent frequency PMP BSs located outside the grid illustrated in Figure 22, which would require interference avoidance, thereby further restricting the pointing angle possibilities.

Clearly, close coordination is required under these conditions.

Examination of Table 17 shows that if a single guard channel is inserted, then the PTP link could be operated anywhere within the grid of Figure 22 to within a few hundred meters of the PMP BSs so long as care is taken to avoid the PTP main beam pointing towards the BS. Although less constraining, again detailed coordination would be required to account for the whole deployment of PMP BSs.

6.6.3.2 Class B3 and Class B4

These classes refer to interference between the PTP station and PMP SSs. Care should be taken to understand the antenna decoupling angles α and β by reference to Figure 12 and Figure 13 in ETSI TR 101 853 (2000-10) [B16].

Table 18 is an extract of results for PMP terminal station interference into a PTP station. In this example, the PTP link was sited 5 km away from the BS, and Table 18 gives the *C*/*I* values that are less than 30 dB at the PTP receiver for a range of PTP decoupling angles and SS decoupling angles. Additionally, the frequency offset is one channel being consistent with a NFD assumption of 27 dB.

Although Table 18 is truncated, the *C*/*I* for α equal to 0° becomes greater than 30 dB at β of 52°. This shows that in the situation where the SS decoupling angle is 0, the PTP link should point away by at least 52° if operating in the AdjCh to the PMP SS. Considering that SS could be located in any position in a sector facing the PTP link, this could place considerable constraints on the PTP pointing angle illustrated in Figure 20. The problem becomes more severe when a full deployment of PMP cells is considered, employing a frequency reuse plan. If the PTP link is situated at 10 km from the BS, the decoupling angle required drops to 24°.

Table 18—Class B3, NFD=27 dB (i.e., AdjCh), sample *C*/*I* at Rx of PMP SS[a]

PTP decouple β	α	**0**	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**55**
	gain at α	**32**	**26.8**	**15**	**12.5**	**10**	**8.75**	**7.4**	**6.1**	**4.9**	**3.6**	**2.3**	**2**
	d_1 (km)	**8.70**	**8.69**	**8.64**	**8.57**	**8.48**	**8.35**	**8.20**	**8.03**	**7.83**	**7.62**	**7.38**	**7.12**
0		–5.6	-0.4	11.4	13.8	16.2	17.3	18.5	19.6	20.6	21.7	22.7	22.7
1.5		–5.6	-0.4	11.4	13.8	16.2	17.3	18.5	19.6	20.6	21.7	22.7	22.7
2.0		–2.9	2.3	14.0	16.5	18.9	20.0	21.2	22.3	23.3	24.3	25.4	25.4
2.5		-0.2	4.9	16.7	19.1	21.5	22.7	23.9	25.0	25.9	27.0	28.0	28.0
3.0		2.4	7.6	19.4	21.8	24.2	25.3	26.5	27.6	28.6	29.7	-	-
4.5		9.4	14.6	26.4	28.8	-	-	-	-	-	-	-	-
5.8		13.4	18.6	-	-	-	-	-	-	-	-	-	-
7.4		13.9	19.1	-	-	-	-	-	-	-	-	-	-
9.0		14.4	19.6	-	-	-	-	-	-	-	-	-	-
9.3		15.1	20.3	-	-	-	-	-	-	-	-	-	-
10.0		16.4	21.6	-	-	-	-	-	-	-	-	-	-
11.0		17.2	22.4	-	-	-	-	-	-	-	-	-	-
12.0		18.0	23.2	-	-	-	-	-	-	-	-	-	-
13.0		18.8	24.0	-	-	-	-	-	-	-	-	-	-
14.0		19.6	24.8	-	-	-	-	-	-	-	-	-	-
15.0		20.4	25.6	-	-	-	-	-	-	-	-	-	-
16.0		21.4	26.6	-	-	-	-	-	-	-	-	-	-
17.0		22.4	27.6	-	-	-	-	-	-	-	-	-	-
18.0		23.4	28.6	-	-	-	-	-	-	-	-	-	-
19.0		24.4	29.6	-	-	-	-	-	-	-	-	-	-

Table 18—Class B3, NFD=27 dB (i.e., AdjCh), sample *C*/*I* at Rx of PMP SS[a] *(continued)*

PTP decouple β	α	0	5	10	15	20	25	30	35	40	45	50	55
	gain at α	32	26.8	15	12.5	10	8.75	7.4	6.1	4.9	3.6	2.3	2
	d_1 (km)	8.70	8.69	8.64	8.57	8.48	8.35	8.20	8.03	7.83	7.62	7.38	7.12
20.0		25.4	-	-	-	-	-	-	-	-	-	-	-
22.0		25.7	-	-	-	-	-	-	-	-	-	-	-

[a]Distance BS to SS: d_2 = 3.70 km
Distance BS to PTP: d = 5.00 km
α_{max} = 54 °

Table 19 is an extract from calculations in the same scenario, but with the PTP link operating with one guard channel separation from the PMP SS station. This is reflected in a NFD of 50 dB.

Table 19—Class B3, NFD=50 dB (i.e., 1 guard channel), sample *C*/*I* at PTP Rx of PMP SS[a]

PTP decouple β	α	0	5	10	15	20
	gain at α	32	26.8	15	12.5	10
	d_1 (km)	8.70	8.69	8.64	8.57	8.48
0		17.4	22.6	-	-	-
1.5		17.4	22.6	-	-	-
2.0		20.1	25.3	-	-	-
2.5		22.8	27.9	-	-	-
3.0		25.5	-	-	-	-
4.5		-	-	-	-	-
5.8		-	-	-	-	-
7.4		-	-	-	-	-
9.0		-	-	-	-	-
9.3		-	-	-	-	-

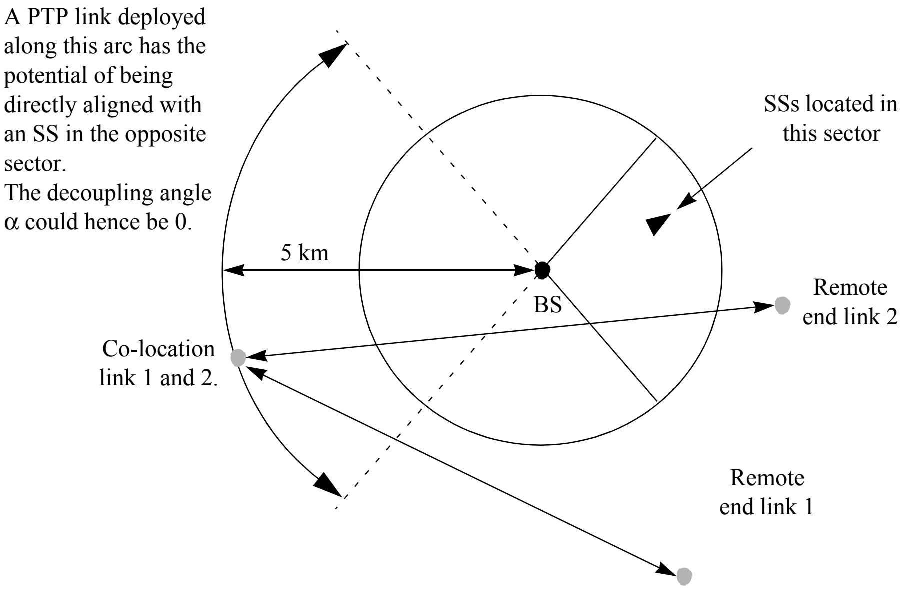
[a]Distance BS to SS: d_2 = 3.70 km
Distance BS to PTP: d = 5.00 km

The excluded decoupling angles are now considerably less being virtually limited to avoidance of boresight coupling. However, this can still impose considerable constraints on the positioning of the PTP link considering that PMP SSs can be located at any point in a facing sector, thereby increasing the chance of boresight coupling.

For Class B4, the *C*/*I* values were less for the same parameter set leading to the conclusion that the interference into the PTP system from the PMP SS is the driver when considering the PMP SS.

Figure 23 shows an example of two PTP links each with one end located on the arc 5 km away from the BS (5 km was assumed in the specific calculation in Table 18). It illustrates the constraint on pointing angle brought about by the need to maintain at least 52° of decoupling angle when no guard band is in place and the reduced constraint with a single guard channel. These results are specific to the calculation results reported in Table 18 and Table 19.

Considerable pointing constraints and detailed coordination are required in either example to consider a whole PMP network.



PTP link 1 is operating in the AdjCh to the PMP SS and is constrained by the need to maintain $\alpha_{min} = 52°$ from any SS in the facing sector.

PTP link 2 is operating on the alternate adjacent channel to the PMP SS and is constrained by the need to maintain $\alpha_{min} = 3°$ from any SS in the facing sector.

Figure 23—Impact of the results displayed in Table 18 and Table 19

6.6.4 Considerations for deployment

Although virtually every parameter used in these calculations is variable and scenario specific, the following broad conclusions can be drawn when considering the operation of individually planned, static PTP links in frequency blocks adjacent to PMP systems in the same geographic area:

- Careful coordination will always be required.
- Regarding PTP stations and PMP BSs, operation in immediately AdjChs may be possible despite the fact that calculations suggest minimum separation distances in the range of several kilometers, even at offset angles moderately removed from main lobe coupling. However, when considered in a wide-scale PMP deployment, there may be further constraints on possible positioning and pointing angles that may be difficult to resolve.
- If a single guard channel is inserted, then minimum separation distances reduce to hundreds of meters, as long as the PTP link avoids main lobe alignment with a PMP BS receiver.
- Improvements in NFD directly reduce the minimum separation required between PTP stations and PMP BS.

- Regarding PTP system and PMP terminal stations, operation in the immediately AdjCh will impose considerable constraints upon pointing angle. This could preclude pointing towards any AdjCh SS in a PMP sector for PTP-to-BS separation distances well in excess of normal link lengths. This problem will be exacerbated by multicell PMP deployment.
- If a single guard channel is imposed, then the PTP system and PMP SS constraints reduce to a need to maintain an angular offset between the PTP main beam and the PMP BS serving the SSs. This angle is virtually a sum of the PTP main beam angle and SS main beam angle to avoid direct PTP to SS main beam coupling.
- Lower EIRP in either system reduces deployment constraints and levels of interference.

6.6.5 Same-area/adjacent-frequency case with multiple PTP link systems operating dynamically

The basis for coexistence is substantially the same as detailed in 5.6.2. However, deployments of multiple PTP links (using the parameters stated in Table 7 in 6.3.3) operating dynamically within a frequency block assignment will usually need two guard channels, when traditional PMP networks are operating in adjacent frequencies in the same area. However, further analysis and simulation have shown that the actual guard frequency required depends on the scenario and on whether the PMP system is considered as a victim or interferer (see summary of analyses in C.2). Thus, as is usually the case, benefit could be obtained from close cooperation and coordination between the affected operators.

6.7 Description of interference evaluation and example scenarios

This subclause describes the models, simulations, and analyses used to derive the guidelines in Table 20. A number of interference scenarios have been identified that include PTP links as one system and a FBWA system as the other. For each scenario, a summary of the methodology for calculating interference levels is described, and a guideline geographical or frequency spacing is derived.

This recommended practice provides guidelines for geographical and frequency spacing between FBWA systems and PTP systems that would otherwise mutually interfere. The guidelines are not meant to replace coordination procedures. However, in many (probably most) cases, by following these guidelines, satisfactory operation will be possible. The information is, therefore, valuable as a first step in planning the deployment of systems. Because many PTP links have protected status, it will often be necessary to carry out further specific calculations or measurements. Any adjustments to system layout can then be made. These adjustments should be relatively small, except in unusual cases.

6.7.1 Interference mechanisms

Various interference mechanisms can reduce the performance of FBWA systems operating within interfering range of PTP 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 FBWA use, different types of systems may be deployed, some conforming to IEEE 802.16 standards and some designed to other specifications. The bands may be shared with PTP system of various kinds. Therefore, a wide range of possibilities is considered in determining the likely interference levels and methods for reduction to acceptable levels. The following are the two main scenarios, each with several variants:

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

The various potential BS-PTP and SS-PTP interference paths need to be considered to determine how much interference will occur. Between any two systems, several interference mechanisms may be operating simultaneously (see 5.4). The geographical or frequency spacing (or both) necessary to reduce interference to acceptable levels is then determined by the most severe mechanism that occurs.

Both worst-case analysis and Monte Carlo simulation techniques have been used to estimate intersystem interference. Each of these methods is described in Clause 5. 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.

6.7.2 Simulations and calculations

Table 20 summarizes the simulations and calculations undertaken. The most appropriate method has been selected, dependent on the scenario and interference path.

Table 20—Summary of simulations and calculations

Scenario	PTP system type	Area/channel	Methodology	Guideline geographical or frequency spacing
PMP BS to PTP	Single link	Adjacent area, same channel	Worst-case analysis	Over the horizon (typically > 60 km). May be reduced to approximately 20 km with antenna pointing offset.
PMP SS to PTP	Single link	Adjacent area, same channel	Worst-case analysis	Over the horizon (typically > 60 km) or combination of large antenna pointing offset and geographical spacing.
PTP to PMP BS	Single link	Adjacent area, same channel	Worst-case analysis	10 km for typical PTP link parameters.
PTP to PMP SS	Single link	Adjacent area, same channel	Worst-case analysis	50–80 km for typical PTP link parameters.
PMP BS to PTP	Single link	Same area, AdjCh	Worst-case analysis	1 guard channel (see Note) plus restrictions on pointing directions.
PMP SS to PTP	Single link	Same area, AdjCh	Worst-case analysis	1 guard channel (see Note) plus restrictions on pointing directions.
PTP to PMP BS	Single link	Same area, AdjCh	Worst-case analysis	1 guard channel (see Note) plus restrictions on pointing directions.
PTP to PMP SS	Single link	Same area, AdjCh	Worst-case analysis	1 guard channel (see Note) plus restrictions on pointing directions.
PMP BS to PTP	Multi-link	Adjacent area, same channel	Worst-case analysis	80 km for typical system parameters.
PMP SS to PTP	Multi-link	Adjacent area, same channel	Worst-case analysis	< 80 km for typical system parameters. Rare cases need greater spacing or coordination.
PTP to PMP BS	Multi-link	Adjacent area, same channel	Monte Carlo simulation	20–24 km for typical system parameters.
PTP to PMP SS	Multi-link	Adjacent area, same channel	Monte Carlo simulation	15 km for typical SS antenna heights. May increase to 40–50 km for very high antennas.

Table 20—Summary of simulations and calculations *(continued)*

Scenario	PTP system type	Area/channel	Methodology	Guideline geographical or frequency spacing
PMP BS to PTP	Multi-link	Same area, AdjCh	Worst-case analysis	Two-channel guard band (see Note).
PMP SS to PTP	Multi-link	Same area, AdjCh	Worst-case analysis	Two-channel guard band (see Note).
PTP to PMP BS	Multi-link	Same area, AdjCh	Monte Carlo simulation	Single-channel guard band (see Note).
PTP to PMP SS	Multi-link	Same area, AdjCh	Monte Carlo simulation	Single-channel guard band (see Note).
NOTE—The guard channel size assumes that the interferer and victim use the same channel size. If they are not equal, then the guard channel should be the wider of the channel sizes of the two systems.				

6.7.3 Results of the analysis

Simulations have been undertaken for many of the interference mechanisms described in 6.7.4. A summary of each method and its results is given in C.2.

6.7.4 CoCh cases

6.7.4.1 BS-to-PTP co-polar/CoCh case

This scenario occurs where the victim PTP receiver is CoCh to the interfering BS transmitter(s). Multiple interferers can occur when the PMP system has multiple cells/sectors with a frequency reuse pattern. The BS-to-PTP interference is not usually the worst case, but has a relatively high probability because of the wide beamwidth of a typical BS antenna.

When the PTP link receiver has protected status, it is essential when planning the system to reduce this kind of interference below the required threshold (typically an aggregate interference level not exceeding –114.5 dBm/MHz). The guideline system spacing for a randomly chosen PTP link and BS antenna pointing direction will be large. For more reasonable distances, use should be made of antenna offsets or terrain and building losses or a combination of these; and specific coordination is, therefore, usually required.

When the victim receiver is part of a multilink PTP system, the requirement for coordination will be reduced.

6.7.4.2 PTP-to-BS co-polar/CoCh case

In general, the victim receiver does not have protected status; therefore, the system can be designed to give a low (but nonzero) probability of exceeding the interference threshold value.

When the interferer is a protected PTP link, a relatively simple worst-case analysis of the interference can be carried out. The severity of the interference will depend on the PTP link length. The probability of worst-case interference is generally low, since it only occurs when two highly directional antennas are aligned.

When the interferer is a system with multiple PTP links, a Monte Carlo analysis is more appropriate. This provides results indicating the probability of a range of interference values. The highest values are usually of very low probability, and a view can be taken on a compromise system spacing that gives a low value of interference in most cases.

6.7.4.3 SS-to-PTP co-polar/CoCh case

This scenario occurs where the victim PTP receiver is CoCh to the interfering SS transmitter(s). Multiple interferers can occur because the PMP cell has multiple subscribers. These may or may not transmit simultaneously, dependent on the systems design. The PMP system may also have multiple cells/sectors with a frequency reuse pattern. The SS-to-PTP interference is usually worse than the BS-to-PTP case. The probability of interference from a single SS is low because both interferer and victim use narrow beam antennas. However, the potential for multiple interferers is significant. These may transmit simultaneously (in which case, the interference must be aggregated) or separately (in which case the probability of a given value of interference may increase).

When the PTP link receiver has protected status, it is essential when planning the system to reduce this kind of interference below the required threshold (typically an aggregate interference level not exceeding –114.5 dBm/MHz). The guideline system spacing for a randomly chosen PTP link and SS antenna pointing direction will be large. For more reasonable distances, use should be made of antenna offsets or terrain and building losses or a combination of these; and specific coordination is, therefore, usually required.

When the victim receiver is part of a multilink PTP system, the requirement for coordination will be reduced.

6.7.4.4 PTP-to-SS co-polar/CoCh case

In general, the victim receiver does not have protected status; therefore, the system can be designed to give a low (but nonzero) probability of exceeding the interference threshold value.

When the interferer is a protected PTP link, a relatively simple worst-case analysis of the interference can be carried out. The severity of the interference will depend on the PTP link length. The probability of worst-case interference is generally low, since it only occurs when two highly directional antennas are aligned.

When the interferer is a multilink PTP system, a Monte Carlo analysis is more appropriate. This provides results indicating the probability of a range of interference values. The highest values are usually of very low probability, and a view can be taken on a compromise system spacing that gives a low value of interference in most cases.

6.7.4.5 BS-to-PTP same-area/AdjCh case

This scenario occurs where the victim PTP receiver is operating in the same area as the interfering BS transmitter(s). Multiple interferers can occur when the PMP system has multiple cells/sectors with a frequency reuse pattern. The BS-to-PTP interference is not usually the worst case, but has a relatively high probability because of the wide beamwidth of a typical BS antenna.

When the PTP link receiver has protected status, it is essential when planning the system to reduce this kind of interference below the required threshold (typically an aggregate interference level not exceeding –114.5 dBm/MHz). This usually requires some additional isolation over and above free space path loss (FSPL). The isolation is normally achieved by using a guard band, typically an integer multiple of the channel spacing of the system(s).

For typical guard band isolation values, a significant proportion of the cell area may be unusable for the PTP link station, unless use is made of antenna offsets or terrain and building losses or a combination of these. Specific coordination is usually required.

When the victim receiver is part of a multilink PTP system, the requirement for coordination will be reduced, because the victim system does not normally have protected status.

6.7.4.6 PTP-to-BS same-area/AdjCh case

In general, the victim receiver does not have protected status; therefore, the system can be designed to give a low (but nonzero) probability of exceeding the interference threshold value.

When the interferer is a protected PTP link, a relatively simple worst-case analysis of the interference can be carried out. The severity of the interference will depend on the PTP link length, the distance from the BS and the amount of guard band isolation between the systems. Typically, satisfactory operation is possible except in an area close to the BS.

When the interferer is a system with multiple PTP links, satisfactory operation of the PTP link station(s) will normally be possible, except in a small area close to the BS. The calculation can, therefore, be carried out in the same way as for the single PTP case.

6.7.4.7 SS-to-PTP same-area/AdjCh case

This scenario occurs where the victim PTP receiver is operating in the same area as the interfering SS transmitter(s). Multiple interferers can occur because the PMP cell has multiple subscribers. These may or may not transmit simultaneously, dependent on the systems design. The PMP system may also have multiple cells/sectors with a frequency reuse pattern. The SS-to-PTP interference is usually worse than the BS-to-PTP case. The probability of interference from a single SS is low because both interferer and victim use narrow beam antennas. However, the potential for multiple interferers is significant. These may transmit simultaneously (in which case the interference must be aggregated) or separately (in which case the probability of a given value of interference may increase).

When the PTP link receiver has protected status, it is essential when planning the system to reduce this kind of interference below the required threshold (typically an aggregate interference level not exceeding –114.5 dBm/MHz). Interference can be reduced by physical spacing and guard band isolation, combined with antenna pointing restrictions.

When the victim receiver is part of a multilink PTP system, the requirement for coordination will be reduced, because the PTP link receiver(s) do not have protected status.

6.7.4.8 PTP-to-SS same-area/AdjCh case

In general, the victim receiver does not have protected status; therefore, the system can be designed to give a low (but nonzero) probability of exceeding the interference threshold value.

When the interferer is a single PTP link, a relatively simple worst-case analysis of the interference can be carried out. The severity of the interference will depend on a number of factors including the PTP link length, antenna orientation and guard band isolation. The probability of worst-case interference is generally low, since it only occurs when two highly directional antennas are aligned.

When the interferer is a system with multiple PTP links, a Monte Carlo analysis is more appropriate. This provides results indicating the probability of a range of interference values, for a given guard band isolation. The choice of guard band is a compromise that gives a low probability of interference in most cases, so that occasional coordination may be needed between PTP link stations and SSs that have the worst alignment and are close together.

6.8 Mitigation techniques for coexistence between FBWA and PTP systems

In order to facilitate coexistence between FBWA PMP systems and PTP systems operating in adjacent frequency blocks in the same area, a minimum separation and angular decoupling are needed between the PTP site and any BS site. To provide the maximum decoupling, the best possible PTP antenna RPE performance is preferable. This is described further in ETSI EN 301 215-2 (2002-06) [B12].

For CoCh systems operating in nearby areas, adequate geographical spacing is necessary between the systems. For interference to protected PTP links, specific calculation will usually be necessary. However, where the victim is a multilink system with multiple PTP links, it may be possible to take into account the additional attenuation provided by buildings and terrain

6.8.1 Impact of buildings and terrain on CoCh interference

Systems with multiple PTP links can make use of terrain and buildings to reduce interference. The reduction in interference serves two functions:

- It reduces internal interference, thus allowing increased frequency reuse and significantly improved spectral efficiency.
- It reduces external interference, so that geographical spacing and guard bands can be reduced.

An analysis of the amount of additional attenuation that can be expected can be derived from Whitehead [B67]. That document refers to mesh systems, but its results could be used also as a guideline for systems with multiple PTP links, where the operator has freedom to assign link frequencies from a block assignment.

The results are derived using a Monte Carlo simulation and give results as cumulative probability distributions. Only the most severe case between a BS and the link system is considered.

The impact of buildings is varied in the model by means of a parameter describing the distribution of building heights (Rayleigh parameter) and using a methodology adapted from ITU-R Recommendation P.838-1 (1999-10) [B40].

6.8.2 Simulation results

In order to assess the impact of different building heights, the parameters in the simulation tool were set as follows:

- Frequency = 28 GHz
- Victim receiver = BS with 90° sector antenna and 19 dBi gain
- Distance from BS = 12 km (any value can be set)
- Link lengths from 50 m to 1000 m
- Link stations placed 1 m above roof height in all cases
- Link antenna gain = 25 dBi
- Rayleigh parameter (building height distribution) varying from 0 to 20 m

The only parameter varied between simulation runs was the Rayleigh parameter. This characterises the building height distribution curve, so that a value of zero would mean that there are no buildings, while a value of 20 m would be a reasonable figure for a city. An example taken from real data, for the large city of Leeds in the United Kingdom, indicates a best-fit value of *R* = 40. The results are shown in Figure 24.

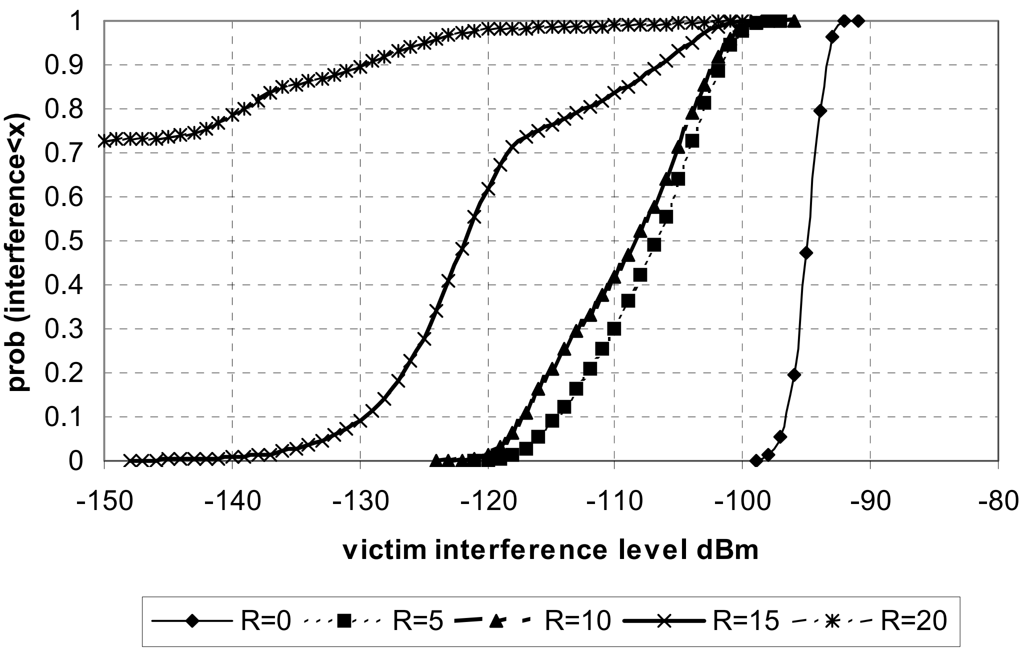


Figure 24—Cumulative probability distributions

It can be seen that for all significant (nonzero) values of the Rayleigh parameter *R*, buildings have a significant impact on the level of interference. The target maximum level for interference is nominally –100 dBm (–114.5 dBm/MHz).

For values of *R* in the range $5 < R < 20$, the proportion of the random trials that exceed the threshold is very small, so the 12 km spacing is likely to be a reasonable value in the great majority of deployments.

For the case where there are no buildings, the highest value is 7 dB to 8 dB above the threshold, so that a wider spacing would then be required. However, a mesh would not be deployed when there are no buildings on which to mount nodes. This scenario is, therefore, highly pessimistic and an unrealistic representation of real deployments.

6.8.3 Conclusions

Buildings have a significant and extremely useful effect on interference, reducing the required CoCh system spacing by a factor of approximately 2. This effect does not rely on the use of any additional mitigation technique and is derived from a simple assumption that all mesh layouts are random. Even relatively low buildings are effective in reducing interference.

7. Coexistence of FBWA systems operating in 2–11 GHz licensed bands

7.1 Introduction

This clause contains guidelines and recommendations for coexistence between various types of FBWA systems operating in the 2–11 GHz frequency range. Because of the wide frequency range and variety of system types, two representative sets of results have been derived, covering operating frequencies around 3.5 GHz and 10.5 GHz. The guidelines and recommendations are supported by the results of a large number of simulations or representative interference cases. The full details of the simulation work are contained in input documents referenced in Annex A.

This clause analyzes coexistence using two scenarios:

- A CoCh scenario in which two operators are in either adjacent territories or territories within radio LOS of each other and have the same or overlapping spectrum allocation
- An AdjCh scenario in which the licensed territories of two operators overlap and 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 FBWA systems, ITU-R Recommendation F.758-2 (2000-05) [B35] details two generally accepted values for the 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 recommended practice, this evaluation has been carried out for $I/N = -6$ dB.

Subclause 7.8 provides interference mitigation measures that can be utilized to solve coexistence problems. Because of the wide variation in SS and BS 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 recommended practice 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 the recommendations 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 recommended practice to make recommendations that touch on intrasystem matters such as frequency plans and frequency reuse patterns.

7.2 Recommendations

7.2.1 Recommendation 3-1

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. This 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 decibels 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, 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.

7.2.2 Recommendation 3-2

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 CoCh interference, this document introduces the concept of using psfd 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 3-5 (see 7.2.5) and Recommendation 3-6 (see 7.2.6) and in 7.5.1.2.

7.2.3 Recommendation 3-3

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 is such that AdjCh operators will be allocated side-by-side frequency channels. As is seen in Recommendation 3-4 through Recommendation 3-7, this is an especially difficult coexistence problem to resolve without co-location of the operator’s cell sites.

7.2.4 Recommendation 3-4

No coordination between PMP systems is needed in a given direction if a transmitter is greater than 80 km (see 7.5.1.2.1) from either the service area boundary or the neighbor’s boundary (if known) in that direction. No coordination between mesh systems is needed in a given direction if a transmitter is greater than 6 km (see 7.5.1.2.2) from either the service area boundary or the neighbor’s boundary (if known) in that direction. No coordination between a PMP system and a mesh system is needed in a given direction if a transmitter is greater than 50 km (see Whitehead [B92]) from either the service area boundary or the neighbor’s boundary (if known) in that direction.

Based on typical FBWA equipment parameters and an allowance for potential LOS interference couplings, subsequent analysis indicates that such a 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 criterion is viewed to be necessary and appropriate for both systems that conform to this recommended practice and systems that do not.

7.2.5 Recommendation 3-5

(This recommendation applies to CoCh cases only.)

Recommendation 3-2 (see 7.2.2) introduced the concept of using psfd 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. If such recommendations are not specified, the following values may be adopted:

The coordination trigger values of –125 dB(W/m^2) in any 1 MHz for 3.5 GHz and –126 dB(W/m^2) in any 1 MHz for 10.5 GHz are employed in the initiative procedure described in Recommendation 3-6 (see 7.2.6). The evaluation point for the trigger exceedance may be at the victim operator's licensed area boundary, at 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 the psdf values which, if present at a typical PMP BS antenna and typical receiver, would result in approximately the –6 dB interference value cited in Recommendation 3-1. 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 interference potential.

7.2.6 Recommendation 3-6

(*This recommendation applies to CoCh cases only.*)

The triggers of Recommendation 3-5 (see 7.2.5) and Recommendation 3-2 (see 7.2.2) 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.

7.2.7 Recommendation 3-7

If the BS emission limits required for TDD/TDD or TDD/FDD operation is not achievable by the employment of ultra-linear BS transmitters, then the utilization of an equivalent guard frequency will be required. 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 OOB emission levels and in some cases is linked to the probability of interference in given deployment scenarios. Useful mitigation techniques include frequency guard bands, recognition of cross-polarization differences, antenna angular discrimination, spatial location differences, use of AAs, 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, use of this guard channel may be achieved in some of the deployment cases. 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.

Three existing coordination procedures are described in B.4, B.5, and B.6. It should be noted that these procedures were originally developed for use at higher frequencies in the range from 23.5 GHz to 43.5 GHz.

7.3 Suggested guidelines for geographical and frequency spacing

Guidelines for geographical and frequency spacing of FBWA systems that would otherwise mutually interfere are given in 7.6 and 7.7 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:

- CoCh 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 21 for TDD/TDD or TDD/FDD operation. In the case where both interfering and victim systems are FDD and operate with the same uplink and downlink channel allocation plan, it may be possible to reduce the guard band requirement for the same-area/AdjCh scenario.

Table 21—Summary of the guidelines for geographical and frequency spacing

Dominant interference path[a]	Scenario	Spacing at which interference is below target level (generally 6 dB below receiver noise floor)
PMP BS to PMP BS	3.5 GHz; adjacent area, same channel	Spacing to at least horizon distance needed (typically 80 km).
PMP BS to PMP BS	3.5 GHz; same area, AdjCh	Combination of isolation (NFD, etc.) and physical spacing is required (typically 0.1–2 km, dependent on available isolation).[b]
PMP BS to PMP BS	10.5 GHz; adjacent area, same channel	Spacing to at least horizon distance needed (typically 80 km).
PMP BS to PMP BS	10.5 GHz; same area, AdjCh	Combination of isolation (NFD, etc.) and physical spacing is required.[a]
Mesh cell to mesh cell	3.5 GHz; adjacent area, same channel	Spacing to at least the cell radius needed.
Mesh cell to mesh cell	3.5 GHz; adjacent area, AdjCh	Spacing to a few hundred meters suffices.

[a] The dominant interference path is the path that establishes the largest geographical or frequency spacing in order to meet the specified intereference target.

[b] Typically a single guard channel is required.

7.4 System description (interferer and victim systems)

7.4.1 System parameters assumed in the simulations

The system parameters assumed in the simulations are based on the data in the Whitehead document [B90] and summarized in Table 22 through Table 24.

Table 22—Parameters for 3.5 GHz systems with a PMP architecture

	Charactistics	Typical values
Deployment	Layout of system(s) including diagrams	Multicell (uniformly distributed).
	Typical sector arrangements and frequencies	Typically 4 sectors per cell, 4 frequencies. Vertical and horizontal polarization both used. Some systems will use AAs, pointing at individual users. FDD and TDD used.
	Propagation	Partly obstructed paths allowed. For coexistence purposes two models were considered. The first uses LOS over the whole interference path, and the second uses LOS up to 7 km and then d^4 beyond that point. Rain fading assumptions negligible. Atmospheric multipath ignored on interfering paths.
	Cell size	Typically 7 km.
	Availability objective	99.9–99.99% of time for 80–90% cell area coverage.
	Number of cells in a system	1 to 25 (typical range).
	Number of terminal stations per megahertz per transceiver per cell	Up to 70.
	Distribution of terminal stations	Uniform per unit area.
	Frequency of operation (for each variant to be studied)	3.4 to 3.8 GHz (use 3.6 GHz for coexistence calculations).
	Duplex method	TDD, FDD, half duplex.
	Channel bandwidth	1.5, 3, 6, 12, 25 MHz (North America). 1.75, 3.5, 7, 14 MHz (Europe) (use 7 MHz for coexistence calculations)
	Antenna characteristics (BS)—nonadaptive	ETSI RPE for 90° sector or similar. Gain = 14.5 dBi.
	Antenna characteristics (SS)—nonadaptive	ETSI RPE or similar. Gain = 18 dBi.
	Antenna characteristics (RS)	Assume same as BS and SS.
	Backhaul links	Separate frequency assignments.
	NFD	See CEPT/ERC Report 099 (2002) [B3].[a]
Receiver	Noise floor	4 dB noise figure upstream. 5 dB noise figure downstream.
	Acceptable level for CoCh interference	I/N = –6 dB (aggregate of all interferers).
Transmitter	Emission mask	See ETSI EN 301 021 (2002-02) [B6].
	Maximum eirp	Not specified.
	Typical mean transmitter power	3 W at BS, 1 W at SS.
	Use of ATPC, steps and range	Uplink only, 2 dB steps, 40 dB range.
	Filter response	Root Nyquist with 25% roll-off factor assumed.

[a] CEPT/ERC Report 099 (2002) [B3] provides NFD values from measurement of a sample of systems operating around 26 GHz. In the absence of any alternatiove data, similar values have been used for this frequency band. This is considered a reasonable asssumption because NFD is a function of emission mask and receiver filtering characteristics rather than carrier frequency.

Table 23—Parameters for 3.5 GHz mesh deployments

	Charactistics	**Typical values**
Deployment	Layout of system(s) including diagrams	Multicell (uniformly distributed).
	Typical sector arrangements and frequencies	Typically 4 sectors per cell, 4 frequencies. Vertical polarization only. Systems may use AAs.
	Propagation	Partially obstructed paths allowed. For coexistence purpose LOS assumed over first 50 m and $d^{2.3}$ for the rest of a link. Nonlink attenuation is assumed to be LOS over the first 50 m, d^3 for the following 500 m, and d^4 for any subsequent distance.
	Cell radius	3.2 km.
	Link distances	Lognormal propagation distribution Arefi [B70] with $\sigma_{PD} = 5$ dB (mean according to link budget). Typically between 50 m and 500 m.
	Availability	97% link availability, approximately equal to 99.9% system availability (for 90% cell area coverage).[a]
	Number of nodes per sector	Up to 100.
	Distribution of terminal stations	Uniform per unit area.
	Frequency of operation	2–6 GHz. Use 3.6 GHz for coexistence calculations.
	Duplex method	TDD.
	Channel bandwidths	6, 7, 12, 14 MHz. Use 7 MHz for coexistence calculations.
	Antenna gain	9 dBi.
	Backhaul links	Separate assignment in block or OOB.
Receiver	Filter response and rejection	See van Waess[B88]. Same physical layer rejection values are (from IEEE Std 802.16a™-2003 [B87]) as follows: — Adjacent (16-QAM-3/4): 11 dB — Nonadjacent (16-QAM-3/4): 30 dB
	Noise floor	5 dB.
	Acceptable level of CoCh interference	$I/N = -6$ dB (aggregate over all interferers).
Transmitter	Emission mask	See ETSI EN 301 021 (2002-02) [B6].
	Tx power (at antenna port)	Mean: –12 dBW.
	Use of ATPC, steps and range	2 dB steps, 25 dB range.

[a] System availability is greater than link availability, based on the assumption of at least two link paths between mesh nodes.

Table 24—Parameters for 10.5 GHz systems with a cellular architecture

	Charactistics	Typical values
Deployment	Layout of system(s) including diagrams	Multicell (uniformly distributed).
	Typical sector arrangements and frequencies	Typically 4 sectors per cell, 4 frequencies. Vertical and horizontal polarization.
	Propagation	LOS paths only. Rain fading important; ITU equations to be used. Atmospheric multipath fading ignored for coexistence purposes.
	Cell size	Typically 7 km.
	Availability objective	99.9–99.99% of time for approximately 50% cell area coverage.
	Number of cells in a system	1 to 25 (typical range).
	Number of terminal stations per megahertz per T/R per cell	70.
	Distribution of terminal stations	Uniform per unit area.
	Frequency of operation (for each variant to be studied)	10.5 to 10.68 GHz.
	Duplex method	TDD, FDD, half duplex.
	Channel bandwidth	3, 6, 12, 25 MHz (North America). 3.5, 7, 14 MHz (Europe) Use 7 MHz for coexistence calculations.
	Antenna characteristics (BS—nonadaptive	ETSI RPE for 90° sector or similar. Gain = 16 dBi.
	Antenna characteristics (SS)—nonadaptive	ETSI RPE or similar. Gain = 25 dBi.
	Antenna characteristics (RS)	Assume same as BS and SS.
	Backhaul links	Separate frequency assignments.
	NFD	See CEPT/ERC Report 099 (2002) [B3].[a]
Receiver	Noise floor	6dB noise figure.
	Acceptable level for CoCh interference	$I/N = -6$ dB (aggregate of all interferers).
Transmitter	Emission mask	See ETSI EN 301 021 (2002-02) [B6].
	Maximum eirp	Not specified.
	Typical mean transmitter power	1 W at BS, 1 W at SS.
	Use of ATPC, steps and range	Uplink only, 2 dB steps, 40 dB range.
	Filter response	Root Nyquist with 25% roll-off factor assumed.

[a] CEPT/ERC Report 099 (2002) [B3] provides NFD values from measurement of a sample of systems operating around 26 GHz. In the absence of any alternatiove data, similar values have been used for this frequency band. This is considered a reasonable asssumption because NFD is a function of emission mask and receiver filtering characteristics rather than carrier frequency.

7.4.2 Medium overview

For relatively short transmission paths, propagation over the 2–11 GHz frequency range is relatively nondispersive. Rain attenuation is negligible at the lower end of the band, but increases with frequency and can be significant for frequencies greater than around 7 GHz. Attenuation of emissions by terrain, foliage, and human-generated structures can be significant. However, diffraction loss is finite. This allows consideration of both LOS and NLOS transmission links.

LOS radio systems in these frequency bands may be a combination of thermal and interference noise-limited. Dispersive multipath is not significant until path lengths become greater than 10 km. For NLOS radio systems, consideration must also be given to the excess path loss experienced from diffraction and the fading experienced from reflective facets that are in motion. Measurement data indicates that this form of fading follows a Rician distribution with parameters set by the characteristics of a specific NLOS transmission path. For severely attenuated NLOS links, the fading distribution characteristics approach those of Rayleigh. A variety of channel models have been developed to group-classify different terrain types. This information is valuable for generalized system design. Simplified channel models for the purpose of coexistence calculations have been developed and are summarized in Table 22, Table 23, and Table 24. Diffraction loss calculations using methods described in ITU-R Recommendation P.526-7 (2001-02) [B42] are included in D.2.

For the typical system and equipment parameters employed in this recommended practice, it has been concluded that high availability links will be required to be LOS. Subsequent coexistence considerations are thus based on an assumption of an LOS primary transmission path.

7.4.3 Interference scenarios

The interference scenarios described in 4.2.1 apply to Clause 7. Victim and interfering systems are assumed to be FBWA networks with a PMP or mesh architecture.

7.5 Deployment and coordination

This subclause provides a recommended structure process to be used to coordinate deployment of FBWA systems in order to minimize interference problems.

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

NOTE—In this subcluase, *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.

7.5.1 Co-frequency/adjacent-area case

7.5.1.1 Methodology

Coordination is recommended between licensed service areas where both systems are operating CoCh, i.e., over the same FBWA frequencies, and where the service areas are in close proximity, e.g., the shortest distance between the respective service boundaries is less than the coordination trigger (see 7.5.1.2). 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.

FBWA operators should calculate the psfd at their own service area boundary. The psfd 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 evaluated for heights up to which reasonably be expected interference to potential devices located within the radio horizon could be expected (as shown in Figure 25). Aggregation may in some cases be needed if the flux contributed by the potential interference sources differs less than 3 dB (which generally indicates possible joint direct main-beam–to–main-beam coupling between those interference sources and the potential victim system).

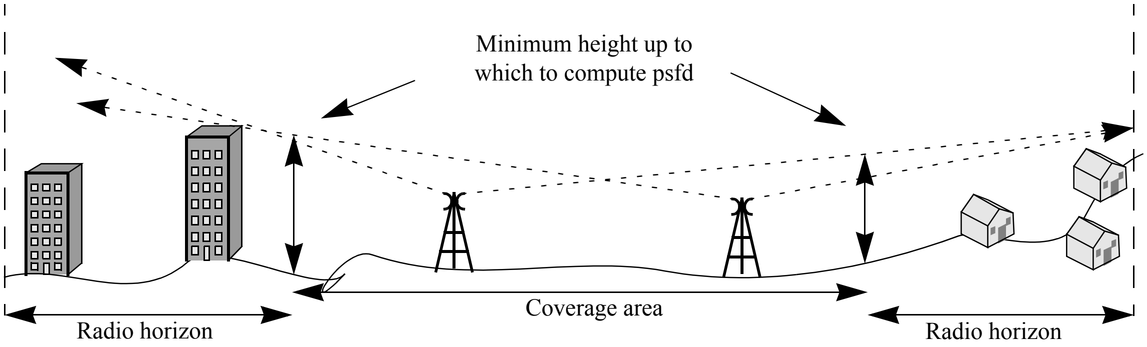


Figure 25—Illustration of psfd computation height at service area boundary

The limits here refer to an operator's own service boundary, because 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 because both existing operators may have to reengineer their systems if service later begins in this intervening land mass. Deployment of facilities that generate a psfd, averaged over any 1 MHz at their own service area boundary, less than or equal to that stated in Table 25, should not be subject to any coordination requirements.

Table 25—Maximum psfd limits

Frequency band (GHz)	psfd dB[(W/m^2)/MHz]
3.5	–125
10.5	–126

7.5.1.2 Coordination trigger

7.5.1.2.1 PMP

Distance is suggested as the first trigger mechanism for coordination between adjacent licensed operators. If the boundaries of two service areas are within 80 km of each other, then the coordination process is recommended.

In the case of sites of very high elevation relative to local terrain, BWA service areas beyond 80 km may be affected. The operator should coordinate with the affected licensee(s).

The rationale for 80 km is based upon several considerations, including radio horizon calculations, propagation effects, and pfd levels.

The radio horizon, defined as the maximum LOS distance between two radios, is defined as follows:

$$R_h = \frac{\sqrt{2k \times R_e} \times (\sqrt{h1} + \sqrt{h2})}{\sqrt{1000}} = 4.12(\sqrt{h1} + \sqrt{h2}) \tag{4}$$

where

R_h is radio horizon (km),

$h1$ is height of Radio 1 above clutter (m),

$h2$ is height of Radio 2 above clutter (m),

k is effective earth radius factor = 4/3,

R_e is earth radius.

D.2 contains details of horizon range calculations for various combinations of BS and SS antenna heights and for two frequency ranges (3.5 GHz and 10.5 GHz). 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). The tables in D.2 also identify the diffraction loss for a spherical earth for the various BS/SS height combinations.

The worst-case interference scenario involves two BSs, as they are typically located on relatively high buildings or infrastructures and hence have greater radio horizon distances than SSs. A typical height for a BS 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 (rounded value). At a distance of 60 km, the worst-case interference scenarios have interference levels above the required limit. Therefore, additional diffraction loss is required. At a distance of approximately 80 km, the losses are sufficient to reduce interference to the required level. Refer to D.2 for details of diffraction loss. There will be cases where the BS equipment may be located on higher buildings, which would produce a greater radio horizon. However, these BSs tend to tilt their antennas downward. This effectively reduces the amount of power directed towards the adjacent BS and, therefore, reduces the interference.

7.5.1.2.2 MP-MP (mesh)

For mesh deployments, generally no LOS exists over the service area boundary. The PMP trigger defined in 7.5.1.2.1 hence needs to be refined for mesh deployments. Observing that the tolerated psdf at the receiver should exceed the aggregate psdf produced by all transmitters (including unspecified path losses), and assuming for simplicity that all nodes contribute equally to the interference provide the worst-case relation:

$$pathloss > P_{\mathrm{Tx}} - 10\log(BW) + G_{\mathrm{Tx}} + G_{\mathrm{Rx}} - 10\log(kT_0) + N_{\mathrm{F}} - (I/N) + \log(Nodes) \quad \mathrm{dB} \tag{5}$$

where

$10\log(kT_0)$ is –144 dBW in 1 MHz [Equipartition Law],

N_{F} is receiver noise figure,

P_{Tx} is mean power at the antenna port,

BW is occupied bandwidth,

G_{Tx} is Tx antenna gain,

$G_{R\mathrm{x}}$ is Rx antenna gain,

I/N is tolerated interference-to-noise ratio,

$Nodes$ is nodes transmitting simultaneously on this channel (near this service area boundary).

The mean *pathloss* is composed of several components. The first component is the reference path loss, which is defined as $20\log(4\pi/\lambda)$ dB, where λ is the wavelength. The remaining components follow the propagation model. In the mesh case, Table 23 (in 7.4.1) specifies the first 50 m LOS, followed by d^3 for the next 500 m, followed by d^4 for any excess distance. Hence:

$$\begin{aligned} pathloss(d) &= 20\log(4\pi/0.09) + 20\log(50) + 30\log(500/50) + 40\log(d/500) \\ &= 40\log(d) - 1 \end{aligned} \quad \text{dB} \qquad \forall d > 500m \tag{6}$$

Combining Equation (5) and Equation (6), using the parameters listed in Table 23, results in a coordination trigger of 6 km for mesh-to-mesh interference. Note that all 100 nodes were assumed active here simultaneously, even though in practical cases a few nodes will at most be active simultaneously. In comparison, using this analysis for PMP would result in a coordination trigger of 80 km for a single BS, similar to the radio horizon. However, should a mesh deployment be installed substantially above the clutter (which is not recommended), then the coordination trigger as specified for PMP should be applied.

7.5.2 Same-area/adjacent-frequency case

As stated in Recommendation 3-4 (see 7.2.4), 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 the size of the wider channel system. This recommended practice does not consider the case where an operator deploys multiple channel sizes within the authorized frequency assignment. If both the interfering and victim systems are FDD and operate with the same uplink and downlink channel arrangement, then it may be possible to reduce or eliminate the guard band requirement. If any one of the systems is TDD, then a guard band is required.

7.6 Coexistence of PMP networks

This subclause indicates some of the models, simulations, and analysis used in the derivation of the recommendations described in 7.2 and the guidelines in 7.3.

7.6.1 Interference mechanisms

Various interference mechanisms can reduce the performance of FBWA systems. Only intersystem interference mechanisms, where interoperator coordination may be appropriate, are considered here. In each frequency band assigned for FBWA use, different types of systems may be deployed, some conforming to IEEE 802.16 standards and some designed to other specifications. Therefore, a wide range of possibilities is considered in determining the likely interference levels and methods for reduction to acceptable levels.

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

- CoCh 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 interference will occur. Between any two systems, several interference mechanisms may be operating simultaneously. The geographical or frequency spacing (or both) necessary to reduce interference to acceptable levels is then determined by the most severe mechanism that occurs.

Both worst-case analysis and Monte Carlo simulation techniques have been used to estimate intersystem interference. These techniques are described in 7.6.2 and 7.6.3. 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. The values are shown in Table 21 and Table 26 with the results as guidelines for nominal geographical or frequency spacing.

7.6.2 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.

7.6.3 Monte Carlo 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 SSs 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 FBWA 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.

7.6.4 Other methods

Two possible other methods, which are not used in this subclause, are the IA method (see 5.7.1.5) and the ISOP method (see 5.7.1.6).

7.6.5 Simulations and calculations

Table 26 summarizes the scenarios analysed. The most appropriate method has been selected, dependent on the scenario and interference path. In the case where both interfering and victim systems are FDD and operate with the same uplink and downlink channel allocation plan, it may be possible to reduce the guard band requirement for the same-area/AdjCh scenario.

Table 26—Summary of the simulations and calculations

Scenario	Frequency	Area/ channel	Guideline spacing	Methodology
BS to BS	3.5 GHz	Adjacent area, same channel	Spacing to at least horizon distance needed (typically 80 km).	Monte Carlo simulation
BS to SS	3.5 GHz	Adjacent area, same channel	Spacing to at least horizon distance needed (typically 80 km).	Monte Carlo simulation
SS to BS	3.5 GHz	Adjacent area, same channel	Typically 40–80 km spacing needed.	Monte Carlo simulation
SS to SS	3.5 GHz	Adjacent area, same channel	Very low probability. Coordination needed for the bad cases.	Worst case (simulation not required)
BS to BS	3.5 GHz	Same area, AdjCh	Combination of isolation (NFD, etc.) and physical spacing is required (typically 0.1–2 km, dependent on available isolation).	Monte Carlo simulation

Table 26—Summary of the simulations and calculations *(continued)*

Scenario	Frequency	Area/ channel	Guideline spacing	Methodology
BS to SS	3.5 GHz	Same area, AdjCh	Isolation needed depends on modulation. In some cases it may be possible to operate in the AdjCh, but typically 1 guard channel is required.	Monte Carlo simulation
SS to BS	3.5 GHz	Same area, AdjCh	Isolation needed depends on modulation. In some cases it may be possible to operate in the AdjCh, but typically 1 guard channel is required.	Monte Carlo simulation
SS to SS	3.5 GHz	Same area, AdjCh	Low probability. Coordination needed for the bad cases.	Worst case (simulation not required)
BS to BS	10.5 GHz	Adjacent area, same channel	Spacing to at least horizon distance needed (typically 80 km).	Monte Carlo simulation
BS to SS	10.5 GHz	Adjacent area, same channel	Spacing to at least horizon distance needed (typically 80 km).	Monte Carlo simulation
SS to BS	10.5 GHz	Adjacent area, same channel	Typically 40–80 km spacing required.	Monte Carlo simulation
SS to SS	10.5 GHz	Adjacent area, same channel	Very low probability. Coordination needed for the bad cases.	Worst case (simulation not required)
BS to BS	10.5 GHz	Same area, AdjCh	Combination of isolation (NFD, etc.) and physical spacing is required.	Monte Carlo simulation
BS to SS	10.5 GHz	Same area, AdjCh	Isolation needed depends on modulation. In some cases it may be possible to operate in the adjacent channel but typically 1 guard channel is required.	Monte Carlo simulation
SS to BS	10.5 GHz	Same area, AdjCh	Isolation needed depends on modulation. In some cases it may be possible to operate in the AdjCh, but typically 1 guard channel is required.	Monte Carlo simulation
SS to SS	10.5 GHz	Same area, AdjCh	Low probability. Coordination needed for the bad cases.	Monte Carlo simulation

7.7 Coexistence of mesh networks

This subclause indicates some of the models, simulations, and analysis used in the derivation of the recommendations described in 7.2 and the guidelines in 7.3.

7.7.1 CoCh intercell interference in a large-scale network

In a multicellular mesh network (see Beyer [B71]), the interference into cells using the same frequency consists of the joint interference from all nodes in the cell. The generated interference depends on the network topology of the cell and the Tx activity of each node within this cell. The logical links that are established by a node determine the transmission power of this node for each of those links (assuming power control is used). When the distance of a logical link is long, the power used, and hence the interference caused, will be higher. On the other hand, if the distance of a logical link is short, it requires more hops to reach the mesh gateway, which increases the number of retransmissions and hence the Tx activity of the average node.

The establishment of logical links is directed by the routing algorithm of nodes within the network, which is typically a complex time-variable algorithm. For the purpose of evaluation, the routing algorithm is restricted to the following two algorithms:

— *Hop minimization and modulation maximization.* Using this strategy, the number of hops is minimized for each node, after which a path is sought from each node to a node with lower hopcount, which has the maximum modulation for that link. This strategy typically leads to the use of very long links to the mesh gateway with low modulation orders using the maximum transmission power. From an intercell interference perspective, this results in an unfavorable scenario.

— *Energy per bit minimization.* Using this strategy, each node seeks to minimize its Tx energy/bit to the mesh gateway, regardless of the number of hops. For WirelessMAN™/HIPERMAN compliant devices, this parameter is distributed through the MSH-NCFG message. This strategy typically leads to the use of short links using very high orders of modulation, but tends to result in a fairly high hop count to reach the mesh gateway. From an intercell interference perspective, this results in a favorable scenario.

In Figure 26 and Figure 27, a typical 100 node scenario, derived using the parameters listed in Table 23, is shown using each of the routing methods. Derivation of these scenarios, in which no synchronization between the mesh gateway sites is assumed, as well as the simulation tool to compute these scenarios, is provided in van Waes [B89]. The thickness of the lines represents the modulation order.

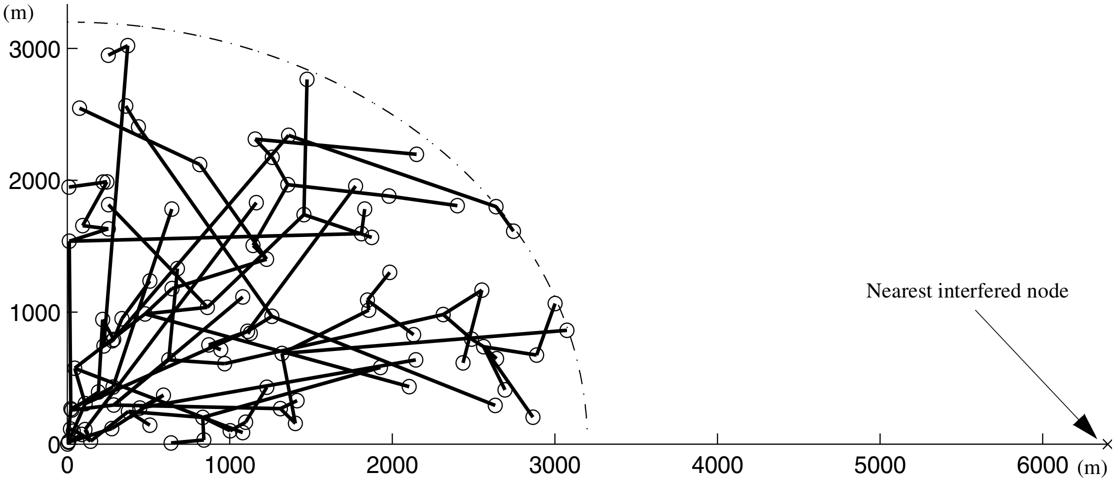


Figure 26—Example mesh scenario using minimized energy-per-bit routing

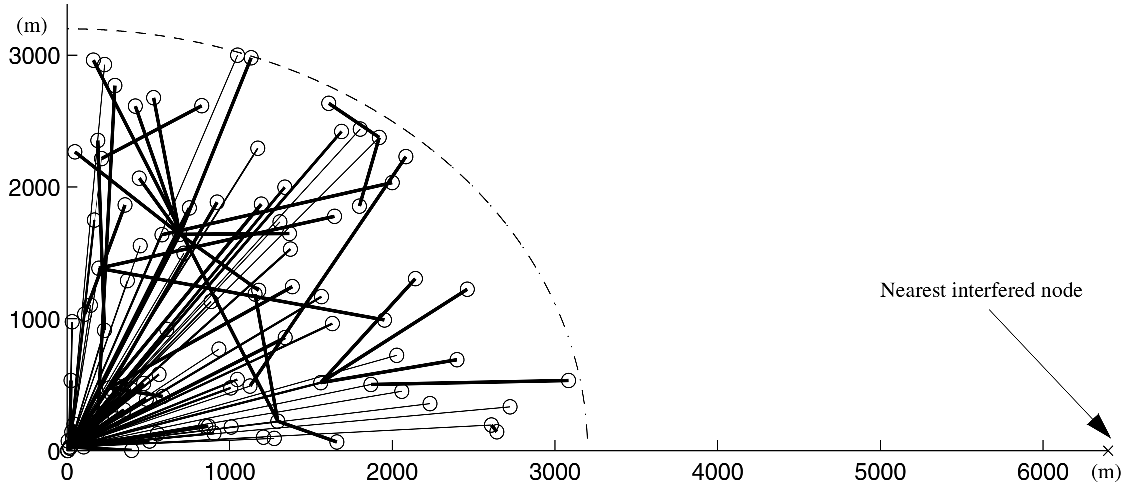


Figure 27—Example mesh scenario using min. hopcount, max. modulation routing

Performing a set of Monte Carlo simulations over random scenarios such as those in Figure 26 and Figure 27, the interference to the nearest node in the nearest CoCh cell is computed. For this, it is assumed that a classical frequency reuse pattern of four is used. The nearest CoCh node is hence twice the cell radius away.

Figure Figure 28 shows the effect of the different routing strategies on the cumulative distribution function (CDF) of the interference to the nearest CoCh node. It should be noted that the probability of interference (i.e., the probability of the interference power exceeding the *I*/*N* margin, which decreases the link budget by 1 dB) is generally relatively low, in the order of 2.5% to 0.6%.

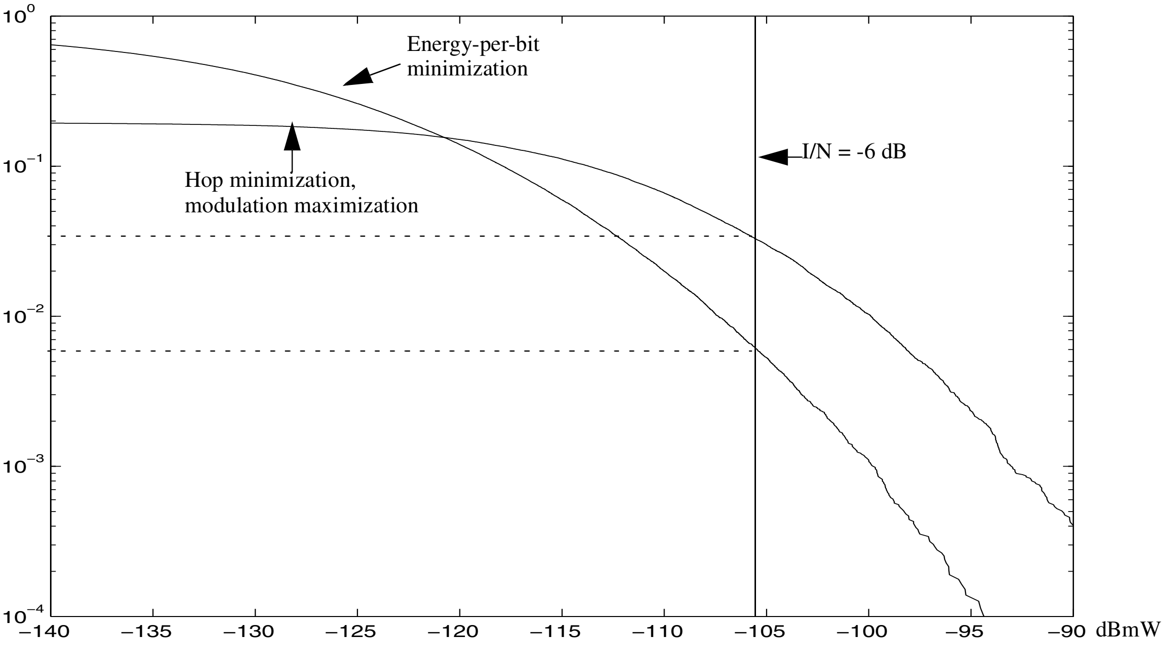


Figure 28—Interference cdf for nearest co-channel node

Energy-per-bit minimization results in a substantially lower interfererence probability due to the typically lower link distances (and related power levels). It does, however, result in higher hop counts, resulting in higher Tx activity factors, which are observable in Figure 28 from the higher probabilities for low interference levels.

7.7.2 CoCh internetwork interference between adjacent areas

When two operators serve adjacent areas, coordination of channel allocations is recommended within the coordination trigger area as described in 7.5.1.2. The probability of interference into the adjacent operator's CoCh cell is computed in an identical fashion as for large-scale networks, with the exception that the distance to the nearest node of the adjacent operator now varies. The resulting curve is hence purely a function of the pathloss model. Using the pathloss model described in Table 23 leads to a decrease of 1 dB for every 280 m. The probability of a decrease in link budget by 1 dB can hence easily be read from Figure 28 by observing the probability for the x-axis value of –105.6 + (*distance of interferer to cell-center – cell radius*)/280 dB.

7.7.3 AdjCh intercell interference in a large-scale network

When deploying mesh gateway sites with cell sectors and a classical frequency reuse pattern, adjacent sectors may be using AdjChs. Performing a Monte Carlo simulation over scenarios similar to Figure 26 and Figure 27, except with the nearest interfered node at 3.4 km (using the depicted 3.2 km cell radius), the probability of interference shown in Figure 29 is derived. It should be noted that the probability of the interference power exceeding the *I*/*N* margin, which decreases the link budget by 1 dB, is generally relatively low, in the order of 0.5% to 0.2%.

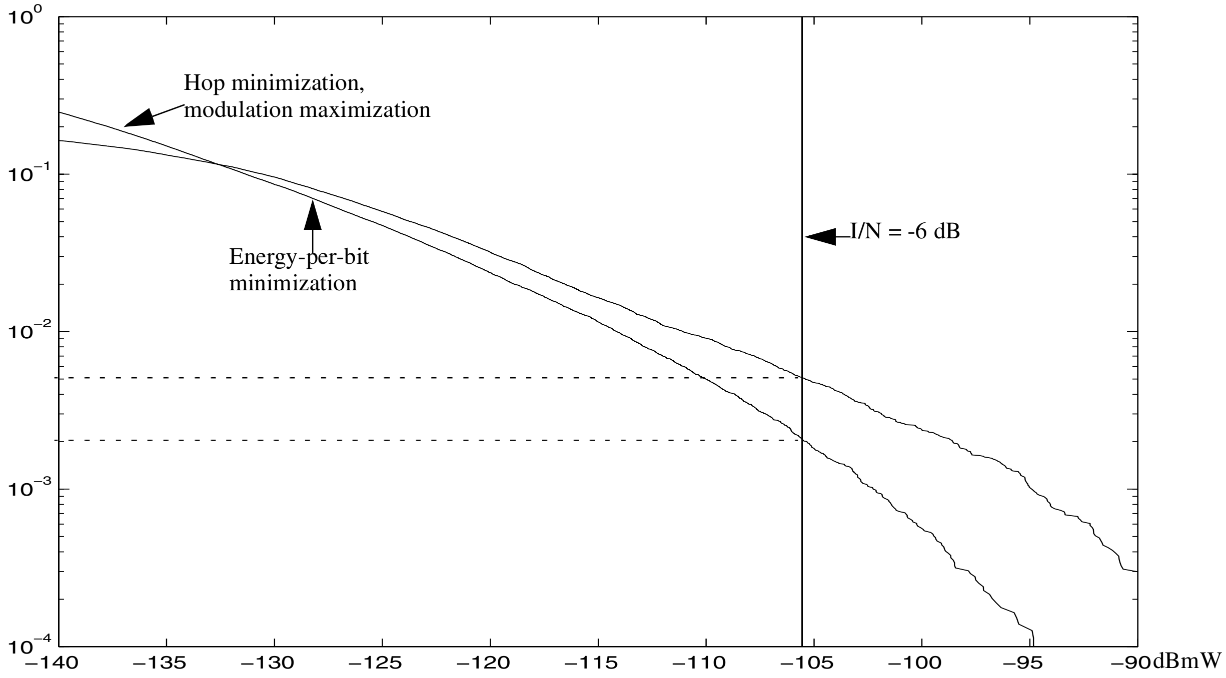


Figure 29—Interference cdf for nearest adj. channel node

7.7.4 AdjCh internetwork interference between adjacent areas

The probability of AdjCh interference between adjacent areas for networks of different operators is identical to that for multicell networks of one operator as derived in 7.7.3.

7.7.5 AdjCh internetwork interference within the same area

When two mesh networks operate on adjacent channels within the same area, potential for interference will depend largely on the location of the nodes in each of the networks. It is, however, to be expected that each network will suffer from bursty interference from the other network, as the isolation between nodes will only be in the order of 90 dB. For this case, operation on alternate AdjChs would in general be recommended.

7.8 Mitigation techniques

A number of mitigation techniques are described in Clause 5. These are also generally of relevance to the types of system analyzed in this Clause 7. In addition, AA techniques may also be useful in some circumstances.

7.8.1 AA techniques

The direct effect of AA on coexistence is due to the fact that the radio frequency (RF) energy radiated by transmitters is focused in specific areas of the cell and is not radiated in all directions. Moreover, beam-forming with the goal of maximizing the link margin for any given user inside the cell coverage area at any given time makes the AA beams' azimuth and elevation vary from time to time.

This characteristic would play a major role in determining the likelihood of interference in both the adjacent area and adjacent frequency block coexistence scenarios. While the worst-case alignment scenario may look prohibitive, because beam-forming may produce a higher gain in the wanted direction, the statistical factor introduced by the use of AA may allow an otherwise unacceptable coexistence environment to become tolerable.

7.8.2 Other characteristics of AAs

Other characteristics could supplement the improvement brought about by the statistical nature of AA operation and warrant further analysis.

Signal processing and the development of spatial signatures associated with the wanted stations may also help to provide some discrimination against interferers in certain directions further reduce the total impact of cumulative interference from neighboring systems in adjacent areas.

For systems operating in adjacent frequencies, the loss of coherency in out-of-band operations reduces the AA gain toward the interferers/victims, which could reduce the amount of interference power.

Annex A

(informative)

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Annex B

(informative)

Additional material for FBWA systems from 23.5 GHz – 43.5 GHz

B.1 Test and measurement/hardware parameter summary

The text in B.1.1 and B.1.2 is based on the test and measurement procedures recommended in Canadian standard IC RSS-191 (2002) [B24].

B.1.1 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.

B.1.1.1 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 (e.g., QAM, QPSK) and does not refer to techniques such as orthogonal frequency division multiplexing (OFDM).

Single-carrier and multicarrier tests should be carried out relative to a virtual block edge (defined in Table B.1). The virtual block edge is located within the assigned band (see Figure B.1). When a transmitter is designed to operate only in part of a band (e.g., because of FDD), 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 B.1—Minimum separation between actual and virtual band edge for different bands

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

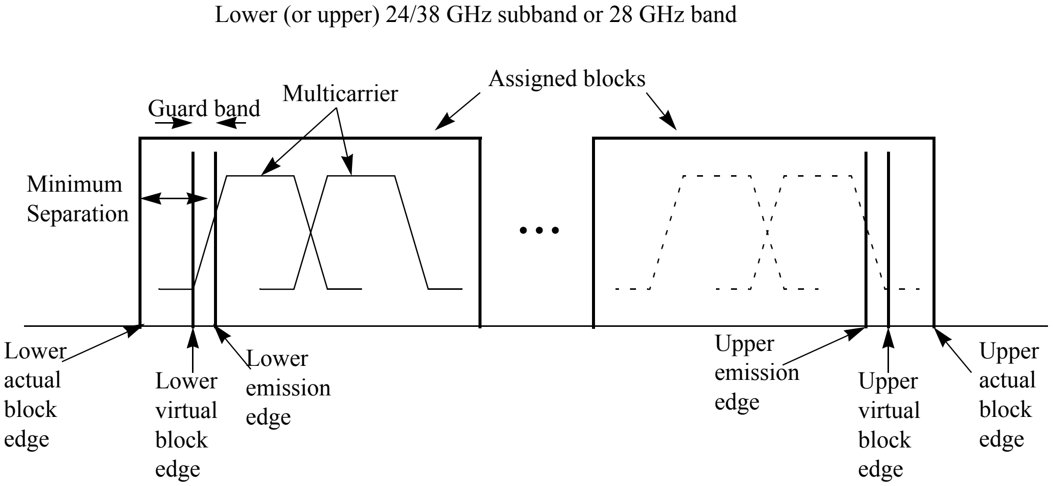

Figure B.1—Band edge definitions

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 in B.1.1.2 and B.1.1.3. If multicarrier operations are intended, then both requirements should be met. *Multicarrier* refers to multiple independent signals (e.g., QAM, QPSK) 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.

B.1.1.2 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 guard band used in the design of the equipment. Record the carrier frequency, f_L; the virtual block edge frequency, f_{VL}; and the guard band, f_{LG}. Then 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 guard band, f_{UG}; and the RF spectrum plot. The guard band 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 required minimum guard band sizes 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 wide-band test signal for the 6.1.3 requirement.

B.1.1.3 Multicarrier 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 in B.1.1.2, in addition to the tests specified in this subclause.

For multicarrier testing, the single-carrier test method of B.1.1.2 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 guard band, 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 guard band sizes, $f_{LG,}$ f_{UG}; the carrier frequencies; and the virtual block edge frequencies.

Notwithstanding the requirements in Table B.1, any equipment that 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 required minimum guard band sizes and the permitted maximum number of carriers or multitransmitters, to ensure that the radios remain compliant to the testing process.

B.1.2 Measuring frequency stability

As discussed in 5.5.1.2, the RF of the carrier should not depart from the reference frequency (i.e., the frequency at 20°C and rated supply voltage) in excess of +10 ppm. The RF 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 stability value in this subclause, 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 in this subclause. The emission tests should be performed using the outermost assignable frequencies that should be stated in the test report.

B.1.3 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. ETSI EN 301 126-2 [B7] covers the following topics for PMP equipment:

- Definitions and general requirements
- Test procedures for frequency division multiple access (FDMA) systems
- Test procedures for time division multiple access (TDMA) systems
- Test procedures for FH-CDMA systems
- Test procedures for DS-CDMA systems

Additionally, drafting activity on another part, catering for multicarrier TDMA equipment, is complete.[15]

B.2 Calculations of psfd

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

$$N_o = 10\log(kT_o) + N_F = -138 \text{ dB(W/MHz)} \tag{B.1}$$

where
N_o is receiver thermal noise psd (dBW in 1 MHz),
10 log (kT_o) is –144 dBW in 1 MHz (Equipartition Law),
N_F is receiver noise figure (6 dB).

At 6 dB below N_o, the interference power level, I_tol, into the receiver is –144 dBW in 1 MHz (–138 – 6).

The psfd at the antenna aperture is calculated as follows:

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

where
P_r is interference power level into receiver (dBW),
λ is wavelength (m),
G is antenna gain (dBi).

B.2.1 In the 20–30 GHz range

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

$$psfd_\text{BS} = -144 - 10\log(0.011^2) - 20 + 10\log(4\pi) = -144 + 39 - 20 + 11$$

$$= -114 \text{ dB (W/m}^2\text{) in any 1 MHz}$$

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

A sample calculation is given in Equation (B.3) to determine the feasibility of meeting the psfd limit between a BS transmitter and BS victim receiver. The formula for psfd is as follows:

$$psfd_\text{victim} = P_\text{TX} + G_\text{TX} - 10\log(4\pi) - 20\log(R) - A_\text{losses} \tag{B.3}$$

where
P_Tx is transmitter power (–25 dBW in 1 MHz),
G_Tx is transmitter antenna gain in the direction of the victim receiver (18 dBi),

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[15] ETSI standards are available from publication@etsi.fr and http://www.etsi.org/eds/eds.htm

R is range (60 000 m),
A_{losses} is atmospheric losses, ~0.1 dB/km.

The values given in parentheses represent typical FBWA parameters.

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

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

The –120 dB(W/m^2) in any 1 MHz value is lower than the –114 dB(W/m^2) in any 1 MHz tolerable level. Therefore, the 60 km range is considered reasonable as a first-level trigger point. Note that this psfd calculation assumes free space propagation and clear LOS, i.e., complete first Fresnel zone clearance.

B.2.2 In the 38–43.5 GHz range

Equation (B.2) shows a dependency of the psfd on the wavelength λ. Thus the psfd limit of –114 dB (W/m^2) in any 1 MHz needs correction to the 38–43.5 GHz band. At 40 GHz, $\lambda = 0.075$ m and substituting into Equation (B.2) (retaining other assumptions) gives –111 dB(W/m^2) in any 1 MHz.

B.3 Description of calculations and simulation methods

For the simulations described in B.3.1 to B.3.3, typical FBWA 26 GHz transmission parameters, as identified in 5.5.1.1, 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 dB to 20 dB was employed for the SS-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 AdjCh bandwidth based on the ETSI Type B emissions mask specified in ETSI EN 301 213-1 (2002-02) [B8]. 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 (2001--02) [B38]. 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 B.3.4 to B.3.8 employed comparable transmission criteria to that described in this paragraph, with the exception that the emissions coupling from a second adjacent carrier was –54 dBc.

Both ETSI PMP antenna RPE masks (see ETSI EN 301 215-1 (2001-08) [B11] and ETSI EN 301 215-2 (2002-06) [B12]) and masks for other typical antennas were employed in the simulations.

B.3.1 SS-to-BS adjacent-area/same-frequency case

These simulations examine interference sensitivity across a service area or business trading area boundary. They examine the interference sensitivity between CoCh interference situations assuming an uncoordinated alignment of interference and victim sectors. Interference impairment is appropriately expressed in terms of psfd defined in terms of dB[(W/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 dB (W/m^2) in any 1 MHz.

B.3.1.1 Simulation model

Figure B.2 illustrates the simulation model. Two CoCh sectors are exposed to each other across a boundary.

As is typical with cellular system engineering analysis, SS locations are located on the periphery of the sectors. The distance between the BS locations is *D* and the distance from an interference SS to the victim BS is R_i. Randomly selected angle locations are set for the interference SS interference positions, and they each establish some angle φ relative to their boresight position and the victim BS. This establishes the SS 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 BS boresight angle is set at some value α and the interference BS boresight is set at some value β. Angle α establishes the RPE antenna discrimination to be expected from the victim BS link.

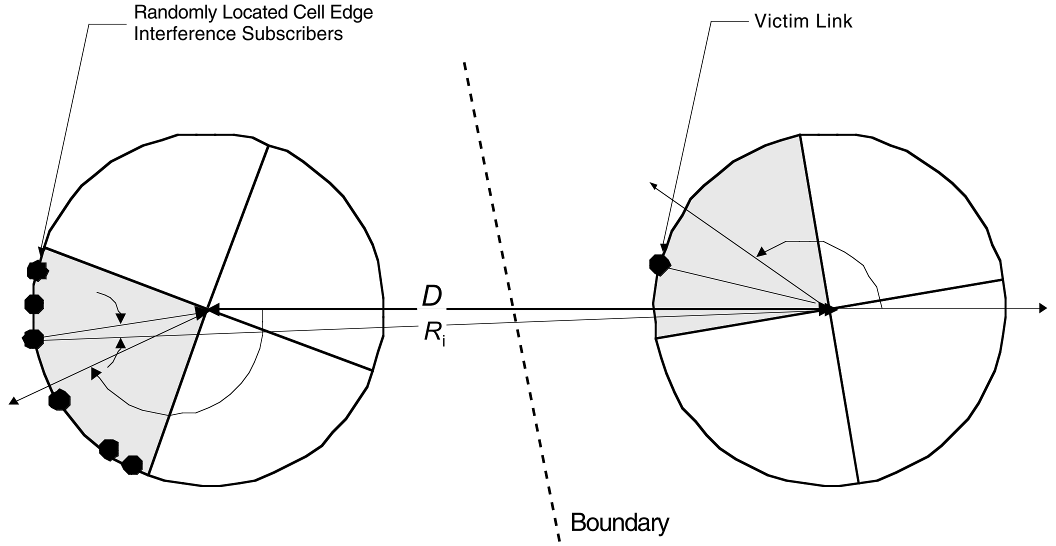


Figure B.2—Simulation model for SS to BS

To complete a simulation, both BS boresight angles are independently incremented in 5^{o} spin intervals. For each spin, the worst *C/I* estimate is computed from the 20 interference locations and entered into a database. For each BS spin, the locations of the interference SS 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 CDF estimate of psfd versus *D*.

B.3.1.2 Simulation results

The main conclusions from this analysis are as follows:

- Typically, at BS separation distances of less than 40 km, 7% to 10% of deployments will require coordination. Beyond 40 km, there were no exposures that exceeded the –114 (dBW/m^2) in any 1 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% to 4% of the interference exposures at less than a BS 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.

— 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 BS 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 recommended practice.

B.3.2 BS-to-SS same-area/adjacent-frequency case

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.

B.3.2.1 Simulation model

Figure B.3 illustrates the simulation model. The interference BS is placed in the victim sector at some parameterized distance *S* between the hub centers.

Relative angular position of the interference BS is set random for each rotational spin of sector alignments. As the interference BS is always deemed to be within the victim sector, only the sector alignment of the interference BS 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 SS locations that experience significant rain loss.

For each rotational spin of the interference BS, 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 where 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 BS 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}.

B.3.2.2 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 BS-to-BS separation distances.

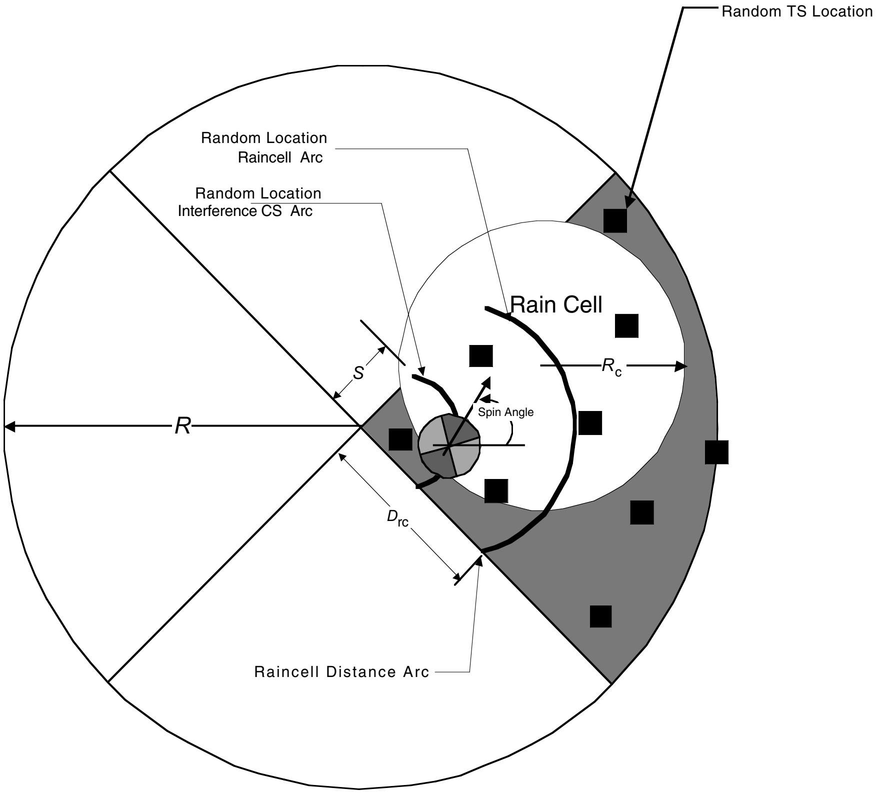


Figure B.3—Simulation model for BS to SS

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 BS separation distances of the order of $0.6R$, R being the cell radius. This is consistent with the simulation conclusions described in B.3.4.

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 B.3.1, the C/I performance was found to be relatively insensitive to antenna RPE outside the main lobe.

B.3.3 SS-to-BS same-area/adjacent-frequency case

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 SS carriers that need to be considered, and both uplink groups apply ATPC, dependent on the relative values of link distance and rain attenuation. In the BS-to-SS analysis, both victim and interference BS 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.

B.3.3.1 Simulation model

The layout model is shown in Figure B.4 where it may be noted that the two sets of SSs likely experience different magnitudes of rain attenuation. Consequently, their ATPC and EIRP will differ as a function of their distance from their serving SS and the adjustment for rain attenuation. It is now convenient to consider the victim BS to be as illustrated in Figure B.5. The rain loss of each of the 20 interference SS links is computed based on their exposure distance within the rain cell. The Tx power of each interference SS 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 BS is then computed based on the transmission criteria of the link.

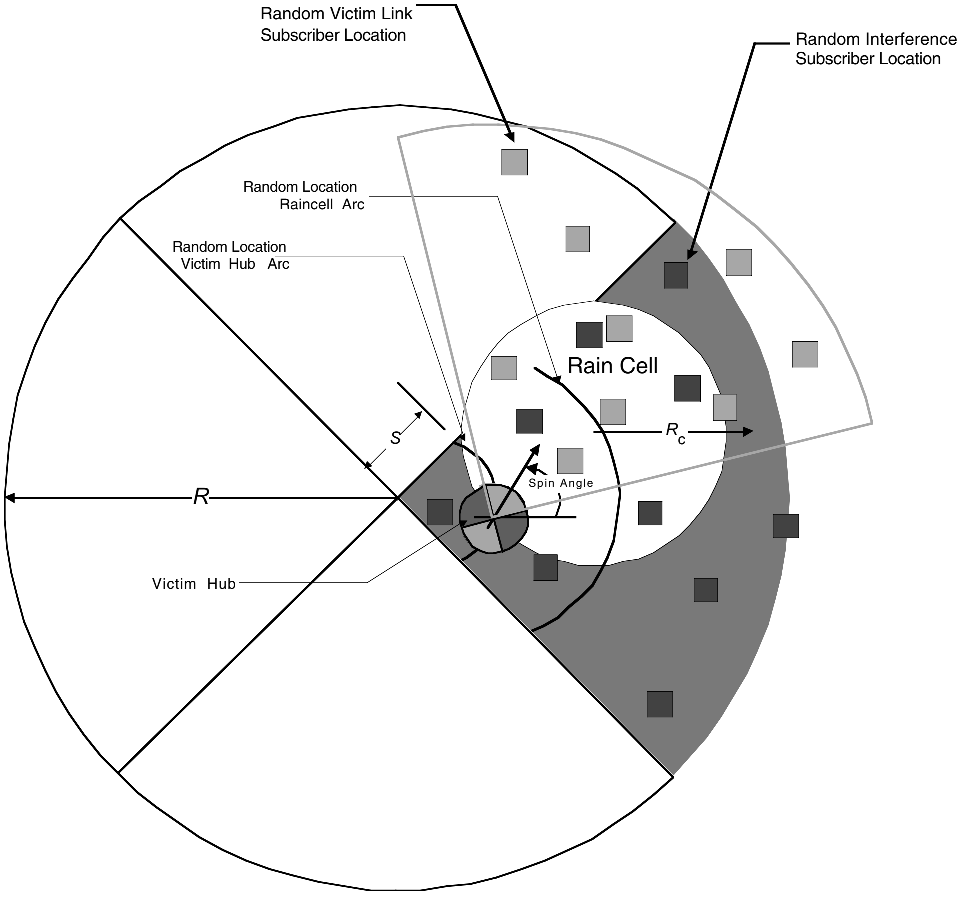


Figure B.4—Layout model

To simplify the complexity of the analysis, it is assumed that victim SS locations are also area proportionally located. Hence, 50% of the victim subscribers are at a distance greater than 0.75*R* (*R* being the cell radius) from the victim BS. 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 0.75*R*. Victim link ATPC is then set accordingly.

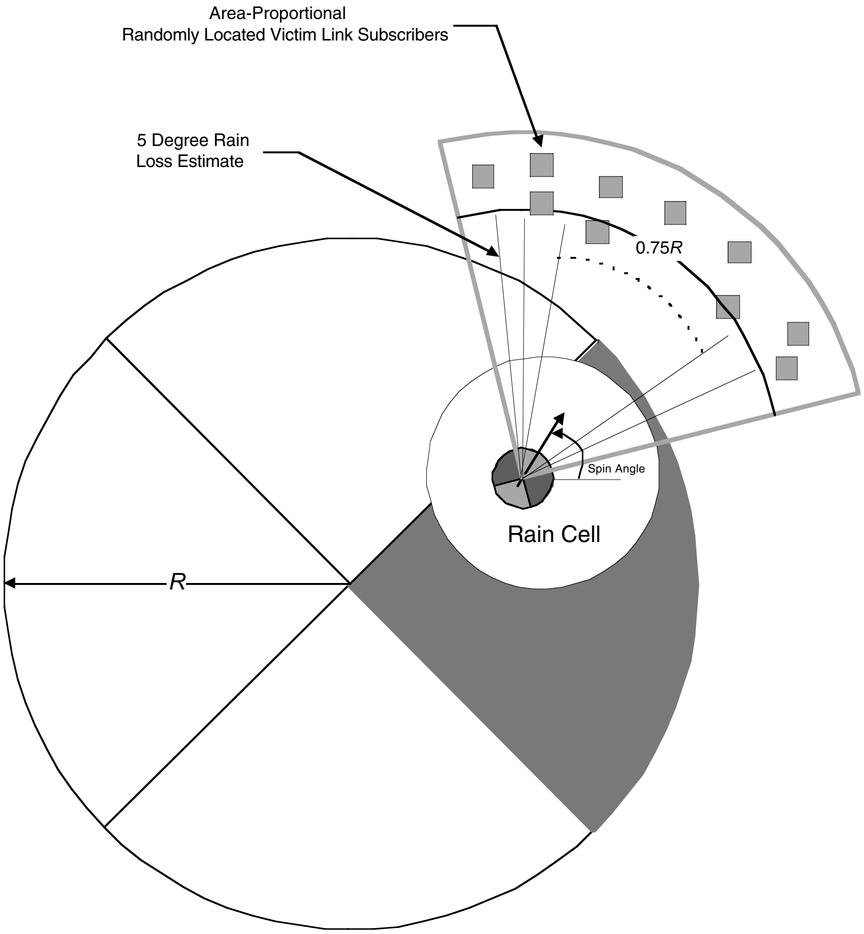


Figure B.5—Victim BS

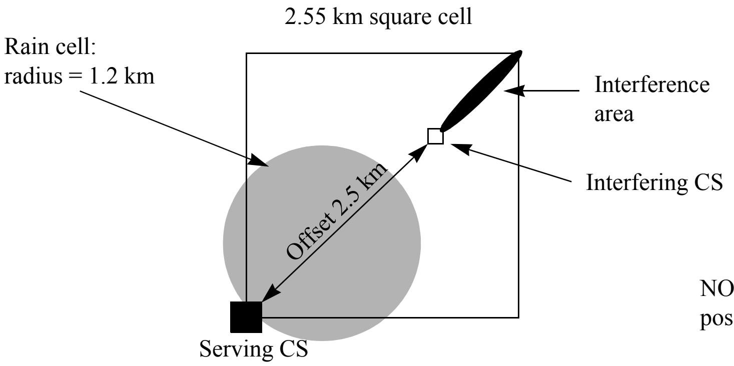
This methodology ensures a 50% SS estimate accuracy for victim link rain loss. However, if the rain loss never exceeds the margin requirement, then all victim link received signals are at the margin requirement. This is the case for many simulation configurations and is guaranteed for clear sky conditions.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

B.3.3.2 Simulation results

As with the BS-to-SS case discussed in B.3.2, 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.

B.3.4 BS-to-SS same-area/AdjCh case, IA method

This simulation derives the 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 SS placed at random will experience interference above the threshold. Analysis shows that the worst case is where the interfering BS is spaced approximately 0.6 times the cell diagonal away from the serving BS and when a rain cell in the most adverse position reduces the wanted signal. This is illustrated in Figure B.6.



NOTE—Worst-case interfering CS position is just outside rain cell.

Figure B.6—Worst-case interference

B.3.4.1 Simulation method

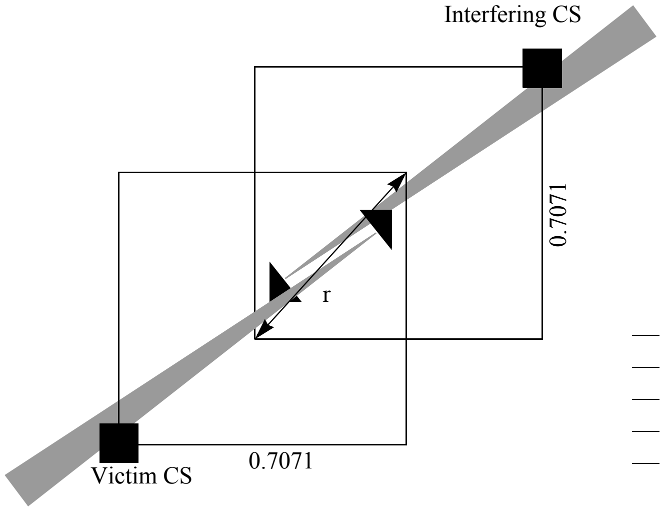
A large number of random SS positions are generated within the cell area. For each position, the wanted and unwanted carrier levels are computed, based on angles, distances, antenna patterns and gains, and the appropriate NFD. The SS positions where the *C/I* is below the required target are counted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

B.3.4.1.1 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 BS 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 SS 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.

B.3.5 SS-to-SS same-area/AdjCh case, TDD only

This simulation computes the *C/I* at a victim SS, the interference arising from another SS 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 B.7.



- — Normalized to unity sector diagonal
- — Overlap parameter *r* varies
- — Assume rectangular antenna RPE
- — Computation based on *C*/*I*, not threshold/*I*
- — Monte Carlo method

Figure B.7—SS to SS, same area, AdjCh, TDD only

B.3.5.1 Simulation method

The overlap parameter *r* is set at a value between 0 (i.e., cell sectors just touching) and 2.5. At a value of 2, the victim and interfering BS locations are the same. The simulation places a number of terminals randomly inside each cell. The program then computes whether 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* 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*.

B.3.5.2 Simulation results

The *C/I* 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* 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* is then at an acceptable level.
- — Rain fading has a neutral or beneficial effect.

B.3.6 SS-to-SS CoCh/adjacent-area case (TDD)

This simulation computes the *C/I* at a victim SS with the interference arising from another SS 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 B.7 for the SS-to-SS same-area case, but with larger values of cell offset.

B.3.6.1 Simulation method

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

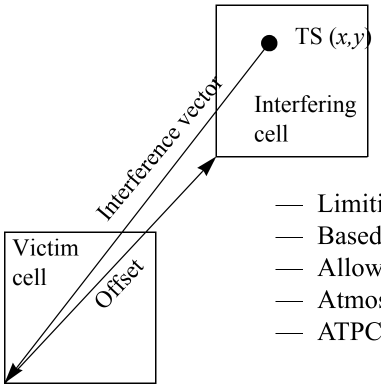
B.3.6.2 Simulation results

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 that is lower than that required to reduce BS-to-BS or BS-to-SS interference to an acceptable level.

It is concluded that SS-to-SS interference is not the limiting case for adjacent area CoCh operation.

B.3.7 SS-to-BS CoCh/adjacent-area case

This simulation applies both to the FDD and TDD case. It is based on the same Monte Carlo method as that used for the AdjCh simulations. The path geometry is shown in Figure B.8.



— Limiting case for FDD cell spacing
— Based on AdjCh 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 B.8—Path geometry for SS-to-BS CoCh simulation (FDD and TDD)

B.3.7.1 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 SS that lies in the IA, but the victim is the distant BS. Atmospheric attenuation and uplink ATPC are taken into account. Additionally, the effect of using different SS antennas is calculated. The SS antenna patterns considered were drawn from ETSI EN 301 215-2 (2002-06) [B12] and from the work of ETSI Working Party TM4 detailed in B.4. Charts are also constructed of the probability of interference against the cell offset value.

B.3.7.2 Simulation results

With the parameters chosen, the interference probability and the IA 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 SS-to-BS CoCh operation an offset of approximately 35 km is a good guideline for uncoordinated deployment.

B.3.8 BS-to-BS CoCh case with multiple interferers

This simulation considers the case of multiple BS interferers in a multicell deployment, interfering with a victim BS (or other station) in a neighboring local MP distribution service (LMDS) system deployment (Figure B.9). 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 SS 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.

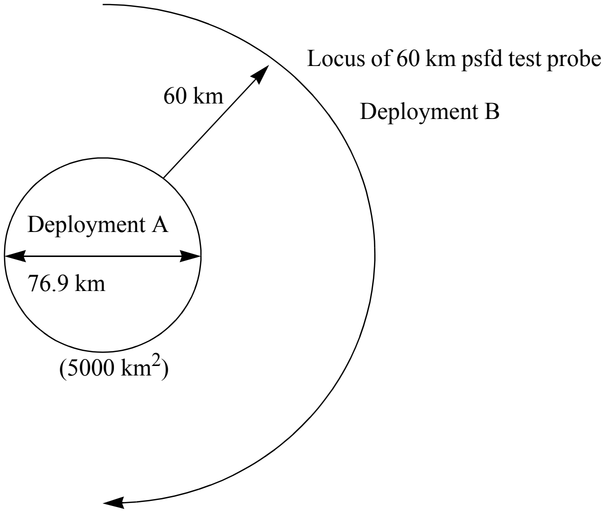


Figure B.9—Simulation geometry

B.3.8.1 Simulation method

The interfering system Deployment A contains a number of BS sites that may be CoCh to the victim station in Deployment B. Calculation shows that up to 70 BS sites could be involved. The victim station is 60 km from the boundary of 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 Deployment 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.

B.3.8.2 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 dB(W/m^2) in any 1 MHz (derived in B.2) is exceeded by 7 dB to 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.

B.3.9 Mesh–to–PMP-BS CoCh/adjacent-area case

This simulation models a high-density mesh network interfering with a PMP BS 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 B.10.

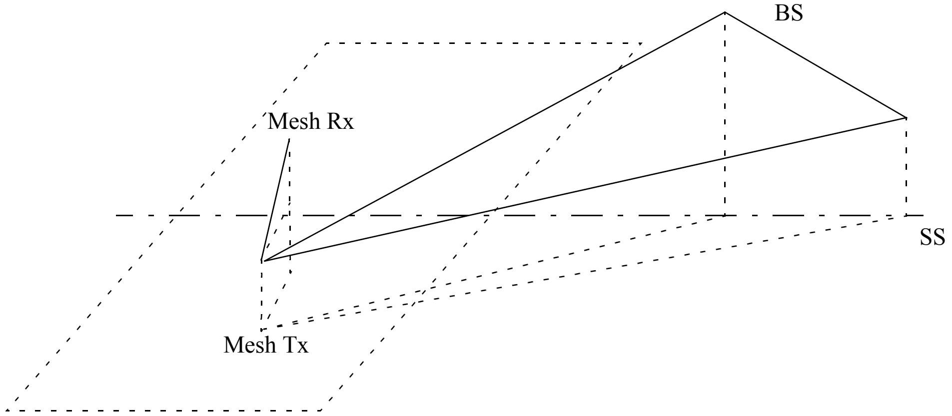


Figure B.10—Mesh–to–PMP-BS, CoCh, adjacent area

B.3.9.1 Simulation method

The main attributes of the model are as follows:

- Monte Carlo simulation with realistic MP-MP system parameters.
- LOS propagation probabilities calculated from Rayleigh roof height distribution function ACTS D5P2B/b1 (1999-06) [B1].
- Interfering power summed at PMP BS or SS using full three-dimensional geometry to compute distances and angles between LOSs and antenna boresights.
- Effect of automatic power control granularity (ATPC) included.
- PMP RPEs for 24-28 GHz band to ETSI EN 301 215-2 (2002-06) [B12] with BS elevation profile ignored for realistic worst case.
- MP-MP antenna RPE model for 24–28 GHz band simulates an illuminated aperture with sidelobes to ETSI EN 301 215-2 (2002-06) [B12].

- Atmospheric attenuation to ITU-R Recommendation P.676-5 (2001-02) [B39]. Cloud and fog to ITU-R Recommendation P.840-3 (1999-10) [B41]. Rain attenuation to ITU-R Recommendation P.838-1 (1999-10) [B40].
- Dry, storm, and frontal weather patterns considered.

The interference target maximum level in the model is –144 dBW in 1 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 in B.3.9.2 are conservative.

B.3.9.2 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 (i.e., 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 (i.e., rain to one side of a line and dry on the other).

The guideline for PMP-to-PMP network separation of 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.

B.3.10 Mesh–to–PMP-SS CoCh/adjacent-area case

This simulation is similar to that for the mesh–to–PMP-BS case. It models a high-density mesh network interfering with a PMP SS associated with a nearby BS sector (hub sector). The SS is pointed towards its serving BS (hub). As with the BS 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 shown in Figure B.10.

B.3.10.1 Simulation method

The method is identical to that for the BS case, except that the antenna RPE for the PMP SS is different (i.e., SS antenna RPE from ETSI EN 301 215-2 (2002-06) [B12]) and the SS always points towards its own hub (BS). The height of the SS 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 BS case.

B.3.10.2 Simulation results

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

Antenna RPE within the mesh was found to be noncritical.

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

B.3.11 Mesh–to–PMP-BS same-area/adjacent-frequency case

This simulation uses a slightly modified model to that for the adjacent-area case. The same full three-dimensional geometry is used in computations, except that the victim hub or SS 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.

B.3.11.1 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 BS 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 three-dimensional geometry is taken into account. The results are computed with various values of NFD appropriate to AdjCh operation and for frequency spacings of one or more guard channels. Dry conditions, storm cells, and rain fronts are considered in the calculations.

B.3.11.2 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 in 1 MHz measured at the victim receiver input.

For AdjCh 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, AdjCh 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 to BS interference, a single guard channel is a suitable guideline for planning deployment of systems, without coordination.

B.3.12 Mesh–to–PMP-SS same-area/adjacent-frequency case

This case is very similar to the same area BS case. The system geometry is nearly identical, except for the typical antenna heights used for the PMP SS. The same full three-dimensional geometry is used in computations, except that the victim hub or SS 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.

B.3.12.1 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 SS 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 three-dimensional geometry is taken into account. The results are computed with various values of NFD appropriate to AdjCh operation and for frequency spacing of one or more guard channels. Dry conditions, storm cells, and rain fronts are considered in the calculations.

B.3.12.2 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 in 1 MHz measured at the victim receiver input.

For AdjCh operation (no guard channel), the probability of exceeding the target interference level is around 12%. As with the BS case, this is too high for uncoordinated operation, although it indicates that with careful deployment, AdjCh 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 to SS 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 SS-to-SS case of PMP networks, so that a result showing that a single guard channel is a satisfactory planning guideline is not unexpected.

B.3.13 General scenario: same-area/adjacent-frequency case

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 BS to PMP BS, PMP SS to PMP SS, high-density mesh to PMP BS, and high-density mesh to another mesh.

Results from worst-case calculations for sample 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 AdjCh. 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 analyses were carried out. Operator deployments were considered with systems that employed identical channelization schemes and system deployments with different channelization schemes.

B.3.13.1 Simulation method

A Monte Carlo analysis was carried out where 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 CDF generated.

PMP BSs are assumed to be transmitting at full power throughout the modeling. ATPC is deployed for both PMP and mesh SSs 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 B.11 were assumed, based upon ETSI EN 301-213 [B8] (112 MHz systems) although modified for ultimate attenuation.

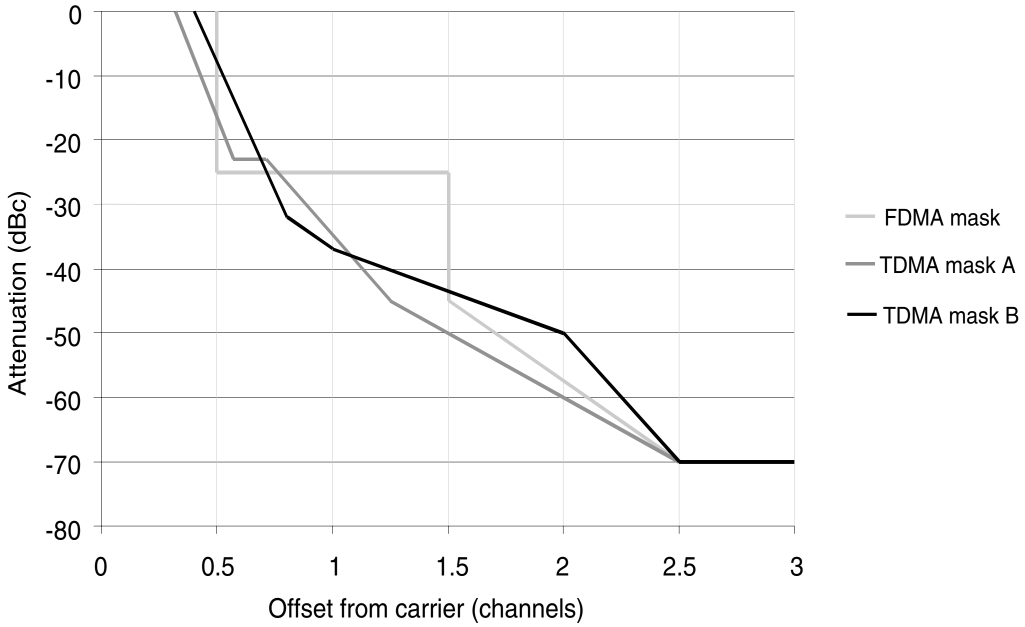


Figure B.11—Tx masks based on –70 dBc floor and spectrum masks from [B8]

The interference limit of –146 dB(W/MHz) is consistent with an *I/N* = –10 dB based on the parameters in B.5.

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

B.3.13.2 Simulation results

Table B.2 summarizes the simulation results.

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.

Table B.2—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 (dB(W/MHz))	Interference limit
Identical	1 channel spacing equivalent	PMP BS to PMP BS	–171	–146 dBW in 1 MHz
		PMP SS to PMP SS	–164	
		High-density mesh to PMP BS	–157	
		High-density mesh to mesh	–144	
Nonidentical (Ratio 4:1)	Sum of half of each nonidentical channel spacing	PMP BS to PMP BS	–147	
		PMP SS to PMP SS	–142	
		High-density mesh to PMP BS	–132	
		High-density mesh to mesh	–120	
Nonidentical (Ratio 4:1)	Sum of each nonidentical channel spacing	PMP BS to PMP BS	–167	
		PMP SS to PMP SS	–167	
		High-density mesh to PMP BS	–156	
		High-density mesh to mesh	–146	

B.4 Work of other bodies

B.4.1 ETSI Working Party TM4

ETSI Working Party TM4 is developing a technical report for publication about the coexistence of PTP and PMP systems using different access methods in the same frequency band [B16]. This report covers the coexistence of PMP FWA systems with other FWA systems and with PTP 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.

In Clause 6 of this recommended practice, use has been made of ETSI TR 101 853 [B16] in developing coexistence guidelines for PTP and FBWA systems.

B.4.1.1 Interference classes

Based upon typical fixed service frequency plans, a set of interference classes are identified. These classes are summarized in Table B.3.

Table B.3—Interference classes

PMP to PMP coexistence		**PMP to PTP coexistence**	
Class A1	BS interferer into victim SS (down/down adjacency)	Class B1	BS interferer into victim PTP receiver (PMP-down/PTP-Rx adjacency)
Class A2	SS interferer into victim BS (up/up adjacency)	Class B2	PTP interferer into victim BS (PTP-Tx/PMP-up adjacency)
Class A3	BS interferer into victim BS (down/up adjacency)	Class B3	SS interferer into victim PTP receiver (PMP-up/PTP-Rx adjacency)
Class A4	SS interferer into SS victim (up/down adjacency)	Class B4	PTP interferer into victim SS (PTP-Tx/PMP-down adjacency)

Having identified the interference classes with typical frequency plans in mind, the range of interference scenarios is 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, Class A1 through Class A4 all can be seen to be possible to a greater or lesser extent. For PMP FDD systems, specific cases only of Class A1 through Class A4 are appropriate. For example, if subbands are defined within the frequency band plan for uplink and downlink transmission directions, then only Class A1 and Class A2 are appropriate. In the case of PMP and PTP deployment, Class B1 through Class B4 all apply to some extent.

B.4.1.2 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.

B.4.1.3 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 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 BS towards the victim SS 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 SS towards the useful BS produces a C/I smaller than a given threshold.
- Class A3: the minimum distance between the two BSs (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 SS towards the victim SSs produces a C/I smaller than a given threshold.

The methodology and the interference parameters summarized in this subclause 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).

B.4.1.4 Resultant considerations

In carrying out this evaluation, a number of considerations have come to light associated with the interference classes identified in Table B.3. These are summarized as follows:

a) Class A1 and Class 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 equivalent-channel guard band is 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 is required.
   2) Separation distance can be minimized with a guard band.

c) Class A4:
   1) Interference is 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) Class B1 and Class B2:
   1) Site sharing is not possible; therefore, minimum distance and angular decoupling are required.
   2) Distance and angular separation can be minimized with a guard band.

e) Class B3 and Class B4:
   1) Site sharing is not possible.
   2) Geometrical decoupling is impossible to achieve due to the spread of SS over the PMP deployment area.
   3) High-frequency separation is required, usually more than one equivalent-channel guard band.

B.4.1.5 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.

B.4.2 Industry Canada (IC)

IC, in consultation with manufacturers and service providers, has conducted studies dealing with coordination between FBWA operators. Technical standards including maximum allowable EIRP, OOB 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. These technical standards are 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.[16]

B.4.3 Radio Advisory Board of Canada (RABC)

The RABC has also conducted technical studies dealing with operator-to-operator coordination issues. RABC Pub. 99-2 (1999) [B51] was issued as an input to the IC regulation and recommends a coordination process using distance as first trigger and two psfd levels that trigger different actions by the operators.[17]

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 B.4 summarizes psfd Level A and Level B for the three frequency bands.

Table B.4—Proposed psfd levels in the 24 GHz, 28 GHz, and 38 GHz bands

Frequency band (GHz)	psfd Level A dB[(W/m^2)/MHz]	psfd Level B dB[(W/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 PTP systems allowed in this band in Canada.

B.4.4 UK Radiocommunications Agency (UK-RA)

The UK-RA has commissioned technical studies dealing with FBWA interoperator coexistence at 28 GHz and 42 GHz.[18] The work studied the issues from the point of view of a regulator wishing to put into place

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[16] The documents (IC Interim Arrangement [B23], IC RSS-191 (2002) [B24], IC SRSP-324.25 (2000) [B27], IC SRSP-325.35 (2000) [B28], and IC SRSP-338.6 (2000) [B29]) dealing with these technical standards can be found at http://strategis.ic.gc.ca/spectrum or http://strategis.ic.gc.ca/epic/internet/insmt-gst.nsf/vwGeneratedInterE/h_sf01375e.html.

[17] Courtesy of the Radio Advisory Board of Canada. RABC Pub. 99-2 (1999) [B51] can be found at http://www.rabc.ottawa.on.ca/e/Files/99pub2.doc.

[18] A report on FBWA coexistence at 28 GHz and 42 GHz and a companion extended study are publicly available from the RA website under the Business Unit/Research–Extra-Mural R&D project section http://www.ofcom.org.uk/static/archive/ra/topics/research/topics.htm#sharing.

coexistence guidelines for FBWA 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.

B.4.5 European Conference of Postal and Telecommunication Administrations/ European Radiocommunications Committee (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, CEPT/ERC Report 099 (2000) [B3],[19] considers both interference scenarios and concludes with recommendations regarding guard frequencies and separation distances. The concepts of ISOP and IA feature extensively in the analyses documented.

B.5 UK-RA coordination process

B.5.1 Introduction

An approach has been proposed to derive guidelines in the UK for FBWA interoperator coordination between licensed areas that abut. It reduces the area in which an operator needs to take some coordination action, allowing him or her 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 5.2.1 through 5.2.10). 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 need 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 simulation in order to test its adequacy and assess the likelihood of harmful interference into a neighboring licensed area.

B.5.2 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 reengineer 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 in 5.4.

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.

B.5.3 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

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[19] CEPT/ERC documents are available from the European Radiocommunications Office at http://www.ero.dk.

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 need 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 SS interference, attention needs to be paid to the possibility of uncorrelated rain fading in certain directions.

If the psfd threshold is exceeded, then the operator 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 on a new, virtual license area boundary for the purposes of coexistence.

B.5.4 Trigger values

Using the methods detailed in B.5.1 through B.5.3 and based upon the parameter values in this subclause, 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 dB(W/m^2) in any 1 MHz
40 GHz band: –98.5 dB(W/m^2) in any 1 MHz

These are associated with the following coordination distance requirements based on the typical EIRPs detailed below so 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 (BS):
  28 GHz band: 27.5 km
  40 GHz band: 18 km
- For SSs
  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 an LOS path between interferers and victim and of the deployment of down-tilted BS antennas in PMP networks, application of these limits can ensure substantially interference-free coexistence between adjacent service areas.

B.5.5 Worst-case interferer calculations

B.5.5.1 BS to BS

The basic link budget equation is as follows:

$$P_{\text{rec}} = EIRP_{\text{tx}} - FSPL - L_{\text{atmos}} + G_{\text{rec}} \tag{B.4}$$

where

P_{rec} is the interference power at the receiver input,
$FSPL$ is the free space path loss = 20 log $(4\pi R_{\min}/\lambda)$,
L_{atmos} is the atmospheric loss ($0.16R_{\min}$dB at 42 GHz or $0.12R_{\min}$ dB at 28 GHz),
G_{rec} is the Rx 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 is as follows:

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

The psfd is as follows:

$psfd = P_{rec} - A_e$

P_{rec} at 18 km for 40.5 GHz = –137.1 dBW in 1 MHz

P_{rec} at 27.5 km for 27.5 GHz = –137.7 dBW in 1 MHz

Therefore, boundary psfd is as follows:

For 27.5 GHz = –102.5 dB(W/m^2) in any 1 MHz

For 40.5 GHz = –98.5 dB(W/m^2) in any 1 MHz

B.5.5.2 SS interference

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

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

Therefore, maximum cell size is as follows:

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 SS is at the cell edge and looking toward a serving BS at the boundary and beyond to a victim BS located within the neighboring network by the coordination distance.

Therefore, worst-case distance is as follows:

For 40.5 GHz = 20.6 km

For 27.5 GHz = 31.6 km

Max EIRP = 11.5 dBW in 1 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 is as follows:

$$P_{\mathrm{rec}} = EIRP_{\alpha} - FSPL - L_{\mathrm{atmos}} + G_{\mathrm{rec}} \tag{B.5}$$

Therefore, the interfering power at the victim BS is as follows:

–147.4 dBW in 1 MHz at 27.5 GHz

–146.3 dBW in 1 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 is as follows:

13 km at 27.5 GHz

8 km at 40.5 GHz

However, it is possible that a combination of nondirect alignment close to boresight 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 SS 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 in 1 MHz.

Therefore, coordination distance is as follows:

16 km at 27.5 GHz

10 km at 40.5 GHz

B.5.6 Parameter values used for trigger derivation and simulations

For the purposes of calculating appropriate coordination zones, psfd trigger levels, and Monte Carlo testing, the system, deployment, and propagation parameter values in Table B.5 were assumed :

Table B.5—Simulation parameter values

Parameter	Value
Nominal channel bandwidth	28 MHz
BS EIRP	15 dBW= 0.5 dB W/MHz
BS antenna gain	15 dBi
BS antenna radiation pattern	ETSI EN 301 215-1 (2001-08) [B11], class CS2

Table B.5—Simulation parameter values *(continued)*

Parameter	Value
BS antenna downtilt	9°
SS EIRP	26 dBW = 11.5 dB W/MHz
SS ATPC assumed	Rx input level maintained at 5 dB above threshold for BER=10^{-6}
SS antenna gain	32 dBi (PMP); 26 dBi (mesh)
SS antenna 3 dB beamwidth	4° (PMP); 9° (mesh)
SS antenna radiation pattern	ETSI EN 301 215-1 (2001-08) [B11], class TS1
SS receiver threshold (BER = 10^{-6})	–111 dBW (QPSK) = –125.5 dBW in 1 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 in 1 MHz (42 GHz) –147 dBW in 1 MHz (28 GHz)
Atmospheric attenuation	0.16 dB/km (42 GHz) 0.12 dB/km (28 GHz)
Rain attenuation	7.2 dB/km (42 GHz) 4.6 dB/km (28 GHz)

B.6 IC coordination process

In Canada, a dual pfd level coordination process is used to facilitate coordination of FBWA systems operating in the 24 GHz, 28 GHz, and 38 GHz bands. The Canadian dual pfd metric is identical in principle and value with the dual psfd metric utilized in Recommendation 5 of 5.2.5 and the discussion in 5.6.3 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 FBWA systems without unnecessary constraints. In addition, the dual pfd process would be used only in cases where mutual sharing arrangements between FBWA operators do not exist. The coordination process being used in Canada for the 24 GHz range is shown in IC SRSP 324.25 (2000) [B27]. Other related documents are, for the 28 GHz band, IC SRSP 325.35 (2000) [B28]; for the 38 GHz band, IC SRSP 338.6 (2000) [B29]; and IC RSS-191 (2002) [B24].[20]

B.7 ICL

B.7.1 Description

In order for different BWA systems to coexist, isolation is required between an interfering transmitter and victim receiver. For the parameters used in this recommended practice, the amount of isolation required can

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[20] These IC documents can be found at http://strategis.ic.gc.ca/spectrum or http://strategis.ic.gc.ca/epic/internet/insmt-gst.nsf/vwGeneratedInterE/h_sf01375e.html.

be easily evaluated being the difference between an interfering transmitter EIRP and the victim receiver interference threshold (translated to EIRP in front of the receiving antenna).

$$Isolation\ required = EIRP_{\mathrm{TX}} - EIRP_{\mathrm{RX}} \quad \mathrm{(dB)} \tag{B.6}$$

where $\mathrm{EIRP}_{\mathrm{RX}}$ is the receiver interference threshold translated into EIRP in front of the receive antenna.

Assuming

Receiver interference threshold	is –144 dBW in 1 MHz,
Transmitter EIRP	is –3 dBW in 1 MHz,
Antenna gain	is 21 dBi,
Frequency	is 28 GHz,

then $EIRP_{\mathrm{RX}} = -144 - 21 = -163$ dBW in 1 MHz and *isolation required* $= -3 + 163 = 160$ dB.

The required loss to ensure that the $I/N = -6$ dB criteria is not exceeded is 160 dB in this example.

This loss can be accounted for by a number of factors, but key contributors are physical separation and frequency separation. Physical separation introduces free space loss. Frequency separation introduces NFD between an offset transmitter and receiver. Other factors can be important depending on the specifics of the deployment, including polarization discrimination, physical blocking, etc.

B.7.2 NFD

The parameter NFD is a key contributor to the isolation required for adequate coexistence that is under the control of the designer. Where the transmitter emission mask is given by G(f) and the receiver fitering charactestics by H(f), then the NFD for a frequency offset Δf is defined as follows:

$$\mathrm{NFD}(\Delta f) = \int G(f)H(f+\Delta f)\,df \tag{B.7}$$

A sample plot of NFD against frequency offset is shown in Figure 12 for an interferer and victim operating in 28 MHz channels. At one channel (28 MHz) offset (AdjCh), the NFD is around –29 dB. At two channels offset (second AdjCh) the NFD is around –49 dB.

Being a function of both the transmitter emission characteristic and the victim receiver filtering, the profile of the plot and hence the NFD values are clearly influenced by design parameters that affect these characteristics. Transmitter emission shaping and excess bandwidth roll-off factors play a large part in determining the overall NFD response.

NFD and attenuation due to physical distance separation can be traded off against each other to some extent depending on the deployment scenario in order to achieve the target isolation figure.

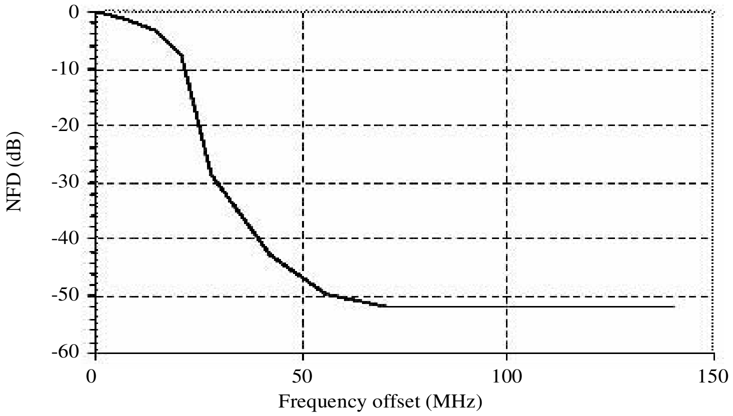

Figure B.12—Example NFD plot

B.7.3 Isolation

Table B.6 illustrates the possible tradeoff mentioned in B.7.2 to achieve a constant isolation requirement of 160 dB (in this example) without use of specific mitigation techniques other than physical separation or frequency offset. Assuming a nominal single guard channel that is 28 MHz wide, the sample NFD values chosen are appropriate to a frequency offset of 56 MHz.

Table B.6—Separation distances/frequency spacing against NFD values

Example NFD at 56 MHz offset (dB)	Single guard channel (fixed), separation required (m)	Separation distance fixed (250 m), estimated frequency separation required (MHz)[a]
45	482	75
50	271	62.5
52	215	55
55	152	40

[a] A frequency separation of 56 MHz equates to the single guard channel scenario.

These considerations should be supplemented by statistical analysis where appropriate.

Annex C

(informative)

Additional material for FBWA with PTP systems from 23.5 GHz – 43.5 GHz

C.1 Sample 38 GHz psfd calculations

The PTP links used in the sample calculations in this annex are assumed to be individually planned static links.

Using the same expressions detailed in Annex B, assuming an operating frequency of 38 GHz ($\lambda = 0.079$ m), a typical BS antenna gain of 20 dBi and a typical PTP link antenna gain of 42 dBi, then the tolerable interference levels are given as follows:

— PMP BS

$$psfd_{\mathrm{BS}} = -144 - 10\mathrm{Log}(0.0079^2) - 20 + 10\ \mathrm{Log}(4\pi) = -111\ \mathrm{dB[(W/m^2)/MHz]} \qquad \text{(C.1)}$$

— PTP link station

$$psfd_{\mathrm{PTP}} = -144 - 10\mathrm{Log}(0.0079^2) - 42 + 10\ \mathrm{Log}(4\pi) = -133\ \mathrm{dB[(W/m^2)/MHz]} \qquad \text{(C.2)}$$

C.1.1 38 GHz: PMP BS Tx into victim PTP link

A sample calculation is given in this subclause to determine the feasibility of meeting the psfd limit between a BS transmitter and PTP victim receiver. The formula for psfd is given as Equation (B.3) in B.2.

Assuming

P_{Tx} is transmitter power (–25 dBW in 1 MHz),
G_{Tx} is transmitter antenna gain in the direction of the victim receiver (18 dBi),
R is range (80 000 m),
A_{losses} is atmospheric losses, ~0.17 dB/km.

Using the radio horizon range of 80 km, the psfd at the victim BS Rx antenna is as follows:

$$psfd_{\mathrm{PTPvictim}} = -25 + 18 - 10\log(4\pi) - 20\log(80\,000) - (80)(0.17) = -129.6\ \mathrm{dB[(W/m^2)/MHz]} \qquad \text{(C.3)}$$

Although the –129.6 dB[(W/m^2)/MHz] value is below the recommended trigger for action, it is above the –133 dB[(W/m^2)/MHz] tolerable level for the PTP link; therefore, even at 80 km some coordination action is advisable. However, at this distance and referring to Table 4 it is likely that intervening terrain and clutter will more than compensate for the 3.5 dB shortfall in loss.

This could be seen as justification for a more stringent psfd trigger threshold if it is considered important to ensure greater protection for neighboring PTP links.

C.1.2 38 GHz: PTP link Tx into victim PMP BS and victim PTP link

A sample calculation is given in this subclause to determine the feasibility of meeting the psfd limit between a PTP transmitter and PMP BS victim receiver. The formula for psfd is given as Equation (B.3) in B.2.

Assuming

P_{Tx} is transmitter power (–25 dBW in 1 MHz),

G_{Tx} is transmitter antenna gain in the direction of the victim receiver (42 dBi),

R is range (80 000 m),

A_{losses} is atmospheric losses, ~0.17 dB/km.

Using the radio horizon range of 80 km, the psfd at the victim BS Rx antenna is as follows:

$$psfd_{\mathrm{PTPvictim}} = -25 + 42 - 10\log(4\pi) - 20\log(80\,000) - (80)(0.17) = -105.6 \text{ dB[(W/m}^2\text{)/MHz]} \quad \text{(C.4)}$$

The –105.6 dB[(W/m^2)/MHz] value is above the –111 dB[(W/m^2)/MHz] tolerable level for the PMP BS; therefore, even at 80 km some coordination action is required. However, at this distance and referring to Table 4, it is likely that intervening terrain and clutter will more than compensate for the 5.5 dB shortfall in loss.

However, if the neighboring victim is another PTP system, then the –105.6 dB[(W/m^2)/MHz] value is around 17.5 dB above the PTP link station tolerable threshold. Where this situation exists, a more stringent trigger threshold would clearly be justified. This situation is not directly addressed in this recommended practice.

C.2 Calculations and simulation methods for PMP-to-PTP interference

This subclause contains a summary of each of the simulations undertaken for the interference scenario between FBWA systems and PTP links. Both individual links, with protected status and systems with multiple PTP links are considered. The full analysis of each scenario is available in an IEEE archive, for which document references are provided.

C.2.1 PMP-BS/SS–to–PTP-link adjacent-area/same-channel case

This subclause analyzes scenarios in which FBWA PMP systems may cause interference to PTP links operating in adjacent areas on the same channels. The PTP links are assumed to be individually licensed and to have protected status.

C.2.1.1 Simulation method

The interferer is either a single transmitter (BS) or a collection of user stations (SS). Because the PTP link must be protected from all cases of interference above the acceptable threshold, a worst-case analysis is appropriate. The analysis is carried out at two frequencies: 25 GHz and 38 GHz.

The interference model for the case where the BS is the interferer is shown in Figure C.1. A corresponding model for the SS case is shown in Figure C.2.

The PMP cell is shown as a circle. A nominal cell radius of 5 km is assumed. The victim station is one end of a PTP link. The distance from the BS or SS to the victim link station is D_i.

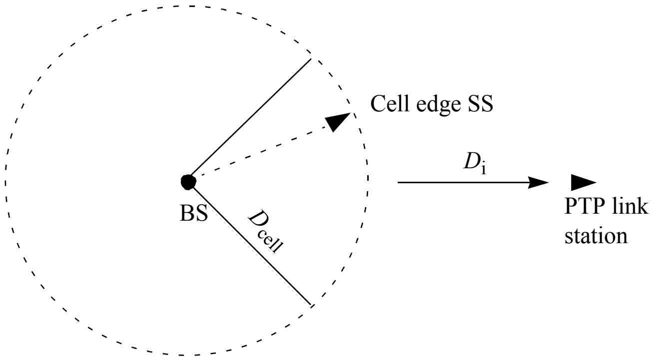

Figure C.1—Interference geometry (PMP BS to PTP link)

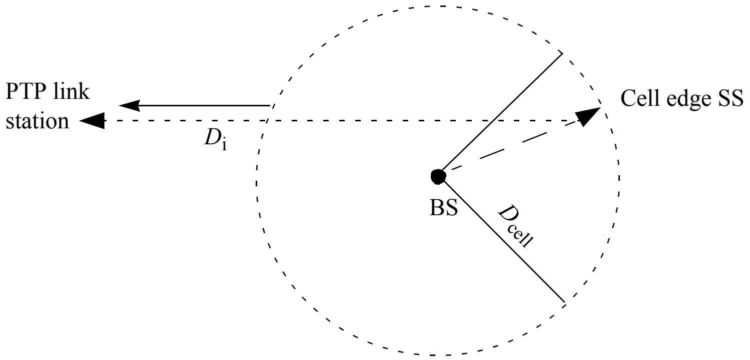

Figure C.2—Interference geometry (PMP SS to PTP link station)

C.2.1.2 Results

In the case where the BS is the interferer, a large system spacing is required, almost certainly corresponding to an over the horizon path. More acceptable distances are possible when the link antenna is pointing at an angle to the path to the BS. In the case where the SS is the interferer, the level of interference is greater and the number of stations that may interfere is higher, although the probability that any one of these would interfere is low. Results are summarized in Table C.1.

The full analysis can be found in Whitehead [B63].

C.2.2 PTP-link–to–PMP-BS/SS adjacent-area/same-channel case

This subclause analyzes scenarios in which FBWA PMP systems may receive interference from point links operating in adjacent areas on the same channels. The PTP links are assumed to be individually licensed and to have protected status. However, the PMP system will not usually benefit in this way, so that higher levels of interference above the normal acceptable threshold level may occasionally be acceptable.

Table C.1—Summary of results

Interference scenario	Frequency	Guideline	Notes
BS to PTP link station	25 GHz	PTP link must be over the horizon or at least 180 km spacing from BS. OR Approximately 20 km spacing with PTP antenna offset.	Coordination usually required. Multiple BS interferers may have to be considered.
BS to PTP link station	38 GHz	PTP link must be over the horizon or at least 180 km spacing from BS. OR Approximately 20 km spacing with PTP antenna offset.	Coordination usually required. Multiple BS interferers may have to be considered.
SS to PTP link station	25 GHz	PTP link must be over the horizon or have a very large pointing offset plus a significant spacing from nearest SS.	Coordination usually required. SS interference is worst case unless terrain losses can be relied on.
SS to PTP link station	38 GHz	PTP link must be over the horizon or have a very large pointing offset plus a significant spacing from nearest SS.	Coordination usually required. SS interference is worst case unless terrain losses can be relied on.

C.2.2.1 Simulation method

In this case, the interferer is a single PTP link station transmitter (the case where there are multiple PTP links is described in a separate paper). Because there is a single interferer, a simple worst-case analysis is appropriate. The analysis is carried out at two frequencies: 25 GHz and 38 GHz. The threshold for acceptable interference is taken as –100 dBm, corresponding to –114.5 dBm/MHz in a 28 MHz channel.

The interference model for the case where the BS is the victim is shown in Figure C.3. A corresponding model for the SS case is shown in Figure C.4.

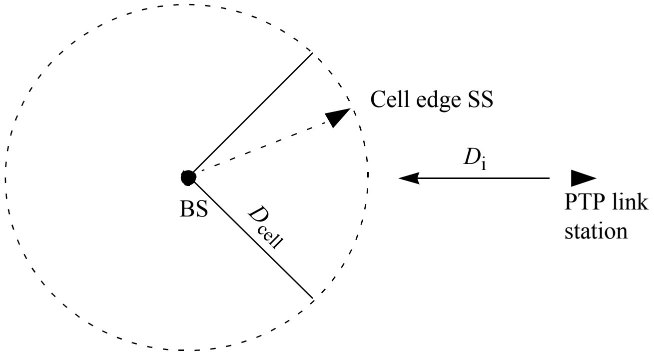

Figure C.3—Interference geometry (PTP link to PMP BS)

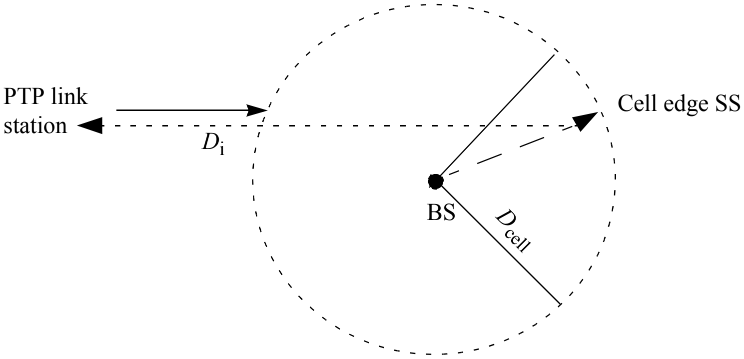

Figure C.4— Interference geometry (PTP link station to PMP SS)

The PMP cell is shown as a circle. A nominal cell radius of 5 km is assumed. The victim station is a BS or SS within the sector. The distance from the BS or SS to the interfering link station is D_i.

C.2.2.2 Results when the BS is the victim

In the case where the BS is the victim and with the assumed set of parameters, a system spacing of the order of 10 km is sufficient. For unusually long link paths, this distance increases, but a small pointing offset is sufficient to achieve an acceptable result.

C.2.2.3 Results when the SS is the victim

In the case where the SS is the victim, the level of interference is greater than for the BS case and the number of stations that may interfere is higher, although the probability that any one of these will interfere is low. For typical PTP link lengths a system spacing of 50 km to 80 km is required. In practice, this will be comparable with, or less than, the typical horizon distance.

In both of the cases in C.2.2.2 and C.2.2.3, the victim system does not have protected status, so that coordination is not essential. It will be sufficient to set a system spacing that gives an acceptably low probability of interference above the normally acceptable threshold.

Results are summarized in Table C.2.

Table C.2—Summary of results

Interference scenario	Frequency	Guideline	Notes
PTP link station to BS	25 GHz	10 km system spacing, with some additional isolation due to PTP antenna offset for longer links (over 5 km at 25 GHz or over 3 km at 38 GHz).	Multiple victim BSs may have to be considered.
PTP link station to BS	38 GHz	10 km system spacing, with some additional isolation due to PTP antenna offset for longer links (over 5 km at 25 GHz or over 3 km at 38 GHz).	Multiple victim BSs may have to be considered.

Table C.2—Summary of results *(continued)*

Interference scenario	Frequency	Guideline	Notes
PTP link station to SS	25 GHz	50–80 km system spacing required. OR Where SS antennas are low, high over-the-horizon losses may dominate (even for shorter distances).	SS interference is worst case and dominates unless terrain losses can be relied on.
PTP link station to SS	38 GHz	50–80 km system spacing required. OR Where SS antennas are low, high over-the-horizon losses may dominate (even for shorter distances).	SS interference is worst case and dominates unless terrain losses can be relied on.

The scenarios are fully analyzed in Whitehead [B62].

C.2.3 PMP-BS/SS–to/from–PTP-link same-area/AdjCh case

The analysis extends, by providing numerical results, work published in ETSI TR 101 853 (2000-10) [B16] in which four interference scenarios are identified:

- Class B1 = PMP BS to PTP station
- Class B2 = PTP station to PMP BS
- Class B3 = PMP SS to PTP station
- Class B4 = PTP station to PMP SS

The main results and conclusions from this analysis are provided in Clause 6 of this recommended practice. The full analysis is available in the Lewis document [B60].

Further information on analysing this case can be found in Whitehead [B64] and [B65]. Both follow the worst-case analysis method and provide broadly similar, though less detailed, conclusions than the analysis referred to in in this subclause.

C.2.4 PMP-BS/SS–to–multiple-PTP-link-system adjacent-area/same-channel case

This subclause analyzes scenarios in which FBWA PMP systems may cause interference to systems with multiple PTP links operating in adjacent areas on the same channels. The PTP links are assumed to have the same status as the PMP system, i.e., they share the band on an equal basis and do not have protected status.

Most of the calculations are the same as for the case where a single PTP link with protected status is the victim. However, the conclusions and resultant guidelines are slightly different.

C.2.4.1 Simulation method

The analysis is carried out at two frequencies: 25 GHz and 38 GHz. In this case, the interferer is either a single transmitter (BS) or a collection of user stations (SS), which may or may not transmit simultaneously. Since the number of PTP links is generally small, the calculation is carried out based on a single victim receiver with worst-case calculation, rather than a Monte Carlo simulation.

An estimate of the effect of building and terrain on the probability of interference can be deduced using the results of Whitehead [B67].

The interference model for the case where the BS is the interferer is the same as shown in Figure C.1. A corresponding model for the SS case is the same as shown in Figure C.2. The threshold for acceptable interference is taken as –100 dBm, corresponding to –114.5 dBm/MHz in a 28 MHz channel.

C.2.5 Results when the BS is the interferer

In the case where the BS is the interferer, in LOS conditions, a system spacing of the order of 180 km may be required, which in most systems will be well over the horizon. Where a pointing offset of a few degrees is also possible, the spacing can be reduced to approximately 20 km.

C.2.6 Results when the SS is the interferer

In the case where the SS is the interferer, the level of interference is greater than for the BS case and the number of stations that may interfere is higher, although the probability that any one of these will interfere is low.

For typical PTP link lengths and any reasonable system spacing (up to the typical horizon distance), a combination of distance and antenna pointing restriction is typically required.

C.2.7 Impact of buildings and terrain

In Whitehead [B67] an analysis was made of the impact of buildings and terrain on mesh/PTP interference into PMP systems. The results shown are for the more adverse BS case. Terrain and buildings were modelled using an adaptation the well-known ETSI TR 101 853 (2000-10) [B16] methodology. The CDF distribution curves are reproduced in Figure C.5.

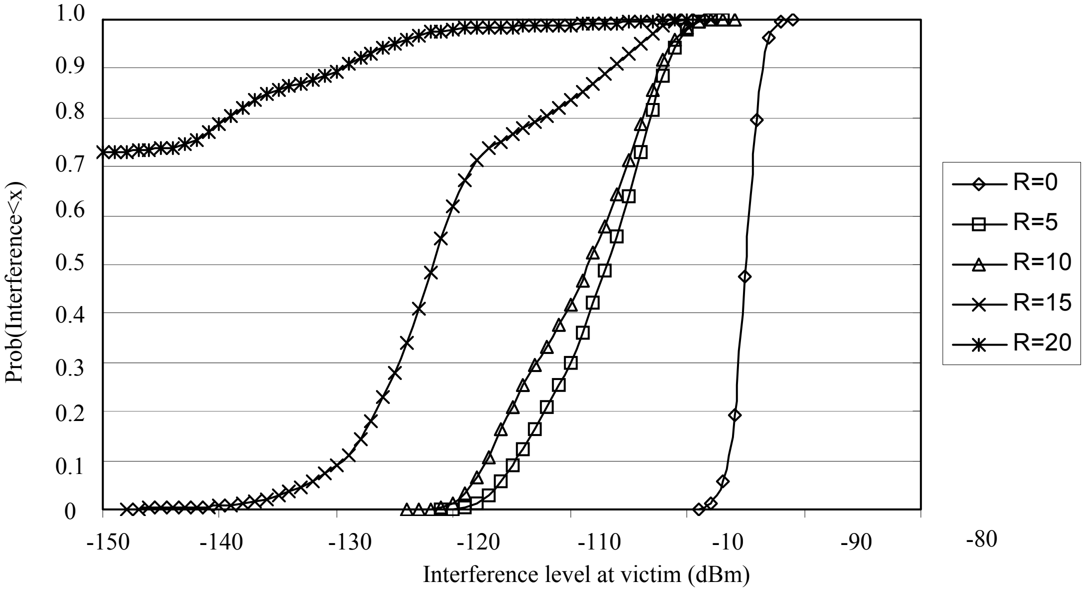

Figure C.5—Interference plotted as cumulative probability curves as function of *R*

For typical urban environments (5 < *R* < 20), where *R* is the Rayleigh parameter), there is a high probability that interference will be significantly attenuated. Although the calculation was based on interference to the PMP system, the geometry for the reciprocal case is similar, and the results should, therefore, give some guide for the case where the PTP system is the victim. Approximately 7 dB to 8 dB of excess loss occurs for a typical range of building heights.

Applying a 7 dB reduction to the BS case reduces the required system spacing to 80 km with no antenna pointing offset and to yet lower values where pointing offset can be relied on.

C.2.7.1 Summary of simulation results

Simulation results are summarized in Table C.3.

Table C.3—Summary of results

Interference scenario	Frequency	Guideline	Notes
BS to multilink PTP system	25 GHz	80 km system spacing. Lower spacing possible with coordination or where the BS antenna is lower than typical.	Multiple victim BSs may have to be considered.
BS to multilink PTP system	38 GHz	80 km system spacing. Lower spacing possible with coordination or where the BS antenna is lower than typical	Multiple victim BSs may have to be considered.
SS to multilink PTP system	25 GHz	BS case usually dominates.	Rare (improbable) cases where SS interference is higher should be dealt with by specific coordination.
SS to multilink PTP system	38 GHz	BS case usually dominates.	Rare (improbable) cases where SS interference is higher should be dealt with by specific coordination.

The scenarios are fully analyzed in Clause 10 of Whitehead [B91].

C.2.8 Multiple-PTP-link-system–into–PMP-system adjacent-area/CoCh case

C.2.8.1 Simulation method

The PTP links are modeled using a simulation tool, which models interference between multiple PTP links and PMP systems. The parameters for the PTP system are taken from Whitehead [B61]. The antenna pattern conforms to the recommendations of Whiting [B69]. A comparison is provided with the case where an ETSI antenna pattern is used.

The simulator computes the power received from a system comprising a number of PTP links at a PMP BS receiver or a PMP SS receiver, in a cell adjacent to the PTP system. The geometry is shown in Figure C.6. Each run of the simulation varies the locations and directions of the PTP links. The results of a large number of trial runs are combined in the Monte Carlo simulation.

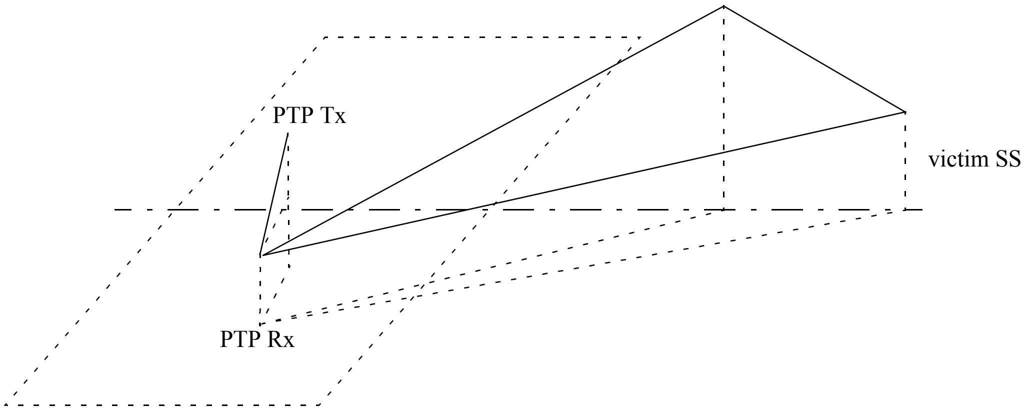

Figure C.6—Interference geometry

The probability of interference LOS is calculated from a model in which building heights are assumed to have a Rayleigh distribution. Most of the scenarios have been simulated with no rain fading. A small number of examples of rain storm conditions were also simulated and found to have negligible impact on the results. All rain scenarios have only a small effect on the results.

The BS Rx antenna is assumed to be a 90° sector aimed directly at the center of the interfering system. A corresponding SS antenna is placed at the cell edge, pointing at the BS.

C.2.8.2 Interfering power calculation

From each link transmitter and, taking account of the LOS probability, the power received by the BS or SS is computed. All these powers are summed, and the result rounded to the nearest dBm and assigned to a histogram bin, so that the relative probability of each power level can be estimated and cumulative probability distributions can be derived.

C.2.8.3 Simulation results for victim BS

Figure C.7 is an example of the cumulative probability distributions, produced from the simulations Whitehead [B68]. Each curve is derived from a series of 10 000 randomly generated system models, with each model simulating the required number of PTP links in the chosen coverage area. The cumulative probability at each point is the point for which the total interference at the victim station will be less than a given value on the *x* axis.

In general, a value of –100 dBm (equivalent to –114.5 dBm/MHz) is low enough to be considered fully acceptable for planning purposes. Thus, where the cumulative probability has reached a value of 1 at the level of –100 dBm, there are no cases above the interference threshold. The geographical spacing corresponding to such a value is then completely safe for planning purposes. The main parameters used to generate the distributions in Figure C.7 are given in Table C.4.

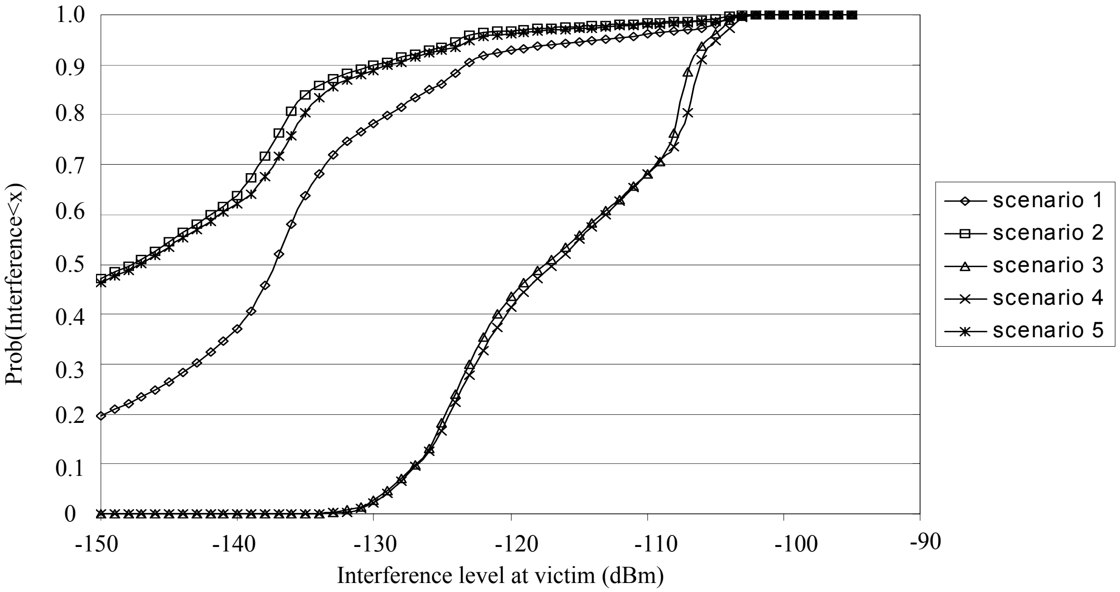

Figure C.7—Example of cumulative probability distributions (BS interference)

Table C.4—Summary of BS interference scenarios using new antenna RPE[a]

Scenario	Building height parameter (m)	Height of interferer above roof level (m)	Links/ km^2	Antenna gain (dBi)	Rain scenario	Distance to BS (km)	% cases where threshold exceeded
1	7	3	10	40	None	20 (18)	0
2	7	1	10	42	None	24 (20)	0
3	0	4	10	42	None	32	0
4	0	4	10	42	Storm	30	0
5	7	3	5	42	None	22 (20)	0

[a] Values in parentheses are derived when using an alternative ETSI antenna RPE.

C.2.8.4 Simulation results for victim SS

The SS interference scenarios are summarized in Table C.5.

Note that, in the case of a victim PMP SS, the level of interference depends strongly on the victim antenna height. Below about 15 m, very little interference is experienced. Above 15 m, the interference increases rapidly. Also, the probability distributions are much flatter than for the BS case, so that to eliminate the last few cases of interference above the threshold, the system spacing has to be increased significantly.

However, SS antenna heights above 15 m have a relatively low probability, so that, in most cases, the BS distance required to reduce interference to the –100 dBm threshold will dominate.

Table C.5—Summary of SS interference scenarios[a]

Scenario	Building height parameter (m)	Antenna height above roof (interferers) (m)	Links/ km^2	Antenna gain (dBi)	Victim antenna height	Rain scenario	Distance to SS (km)	% threshold exceeded
1	7	3	5	40	20	None	15	0.05
2	7	3	5	40	15	None	15 (17)	0
3	7	3	5	40	20	None	40	0.01
4	7	3	5	40	25	None	50	0.06
5	7	3	5	40	10	None	10	0

[a] Values in parentheses are derived when using an alternative ETSI antenna RPE.

C.2.8.5 Conclusions

For most situations, interference to the victim BS determines the required system spacing, which is in the 20–24 km range.

Where SS antennas are on unusually high structures, the SS interference may dominate and the distance may then need to be increased to 40 km to 50 km to reduce the probability of interference to a negligible level. Because the number of such cases is always a very low percentage of the total, it may be more reasonable to apply mitigation techniques than to resort to such large geographical separations

Rain fading is not significant in determining the required geographical spacing.

C.2.9 PMP-system–into–multiple-PTP-link-system same-area/AdjCh case

C.2.9.1 Simulation method

The analysis of this scenario is different from the reciprocal case, which needs a Monte Carlo simulation. In this case, the interferer is a single transmitter with a high probability of being received by a victim PTP station. Thus, a worst-case analysis is appropriate. The interference model is shown in Figure C.8.

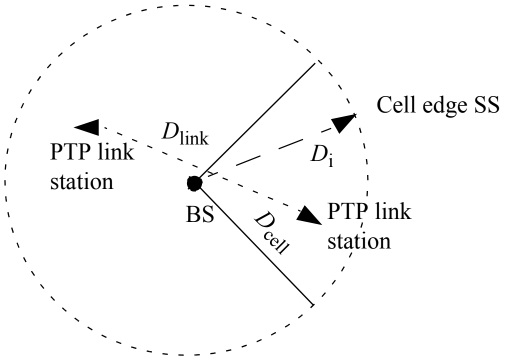

Figure C.8—Interference geometry (PMP BS to PTP link)

The parameters in Table C.6 are assumed for the analysis.

Table C.6—Parameters for PMP to PTP interference scenarios

Parameter	Value	Note
PMP cell radius (D_cell)	5 km	Larger radius leads to worse interference scenario
Frequency	25 GHz	
BS antenna gain	19 dBi	Typical for 90° sector antenna
SS antenna gain	36 dBi	
Link antenna gain	40 dBi	
Nominal SS Rx input level	-73 dBm	Assuming 16-QAM modulation
NFD (1 guard channel)	49 dB	Typical value, from ETSI tables
NFD (2 guard channels)	70 dB	Typical value, from ETSI tables

C.2.9.2 Results of simulations

The value of interference at the victim PTP receiver is calculated for a range of distances and variations in the number of guard channels and antenna pointing offset. The target interference level is less than, or equal to, –100 dBm (28 MHz channel). This corresponds to –114.5 dBm/MHz.

In the case where the BS is the interferer, many link receivers will be illuminated and so the probability of interference is high. With no guard channel, the interference is catastrophic for all reasonable distances. With a single guard channel, the PTP link receiver cannot operate within a guard zone of radius > 500 m, unless the antenna pointing direction is limited. For a two-channel guard band, the zone reduces to approximately 50 m radius, with no pointing restrictions.

In the case where the SS is the interferer, the level of interference is greater, but the probability of interference is lower, due to the narrow beam of the SS antenna.

In this case, even with a two-channel guard band, a significant interference zone exists around each SS and pointing restrictions may have to be considered for a number of PTP links.

C.2.9.3 Conclusions for the PMP-to/from-PTP scenarios

The interference from PMP-to-PTP systems is generally worse than the reciprocal case. In order to assure interference-free operation with a low level of coordination, a two-channel guard band is needed. This is sufficient for the BS-to-PTP case. A single guard channel might be viable provided that mitigation techniques were applied to a small proportion of links in the PTP system.

In the case of SS interference into a PTP system, the interference level can be higher, but the probability lower. A two-channel guard band is not completely effective, but the number of cases requiring coordination will be very low. The same general recommendation of a two-channel guard band is, therefore, considered appropriate.

The full analysis is provided in Whitehead [B66].

C.2.10 Multilink-PTP-system–into–PMP-system same-area/AdjCh case

In general, CoCh systems will not be able to operate successfully in this environment, so that one or more guard channels are required between the systems. The analysis derives guidelines for the size of guard band needed in each scenario.

C.2.10.1 Simulation method

The system geometry is similar to Figure C.8, but with the victim BS or SS placed in the middle of the coverage area of the PTP link system. A Monte Carlo simulation is provided, in which a series of parameters for the PTP links (interferers) and PMP systems (victim BS or SS) can be varied to match the required scenario. Full three-dimensional geometry is taken into account. Each simulation run constructs a random layout of PTP links over the required coverage area. A value of NFD is assigned. The simulation tool plots the results as probability curves (probability of occurrence of a given value of interference and cumulative probability). A target maximum level is set, which in this case is –100 dBm (28 MHz channel). This corresponds to –114.5 dBm/MHz.

C.2.10.2 Interference to PMP BS

The simulation was run with adjacent channel operation and with one guard channel, as shown in Figure C.9.

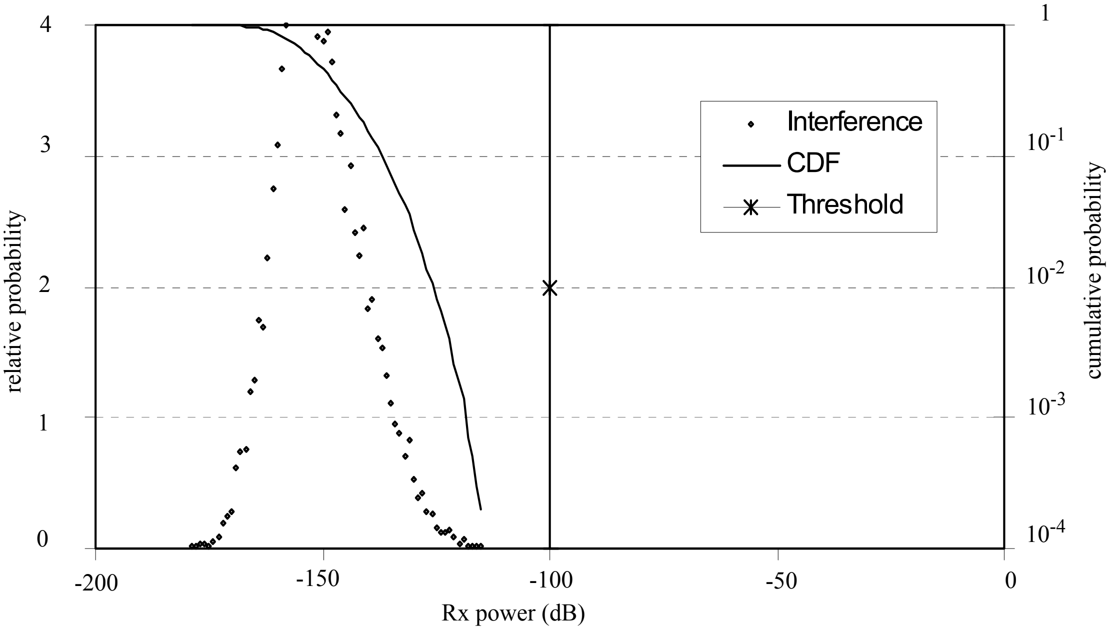

Figure C.9—Interference power profile from PTP to PMP BS (1 guard channel)

It is concluded that a single guard channel is adequate in this scenario for satisfactory coexistence and that operation on the AdjCh could be possible, given a degree of coordination by the operators concerned. However, the other scenarios between systems must also be taken into account when making an overall decision.

C.2.10.3 Interference to PMP SS

Figure C.10 shows the case where the PMP SS is the victim. One guard channel is used. In this case, the probability of exceeding the –100 dBm target level is around 0.1% of random configurations. Thus, coordination would occasionally be required to eliminate all cases of interference.

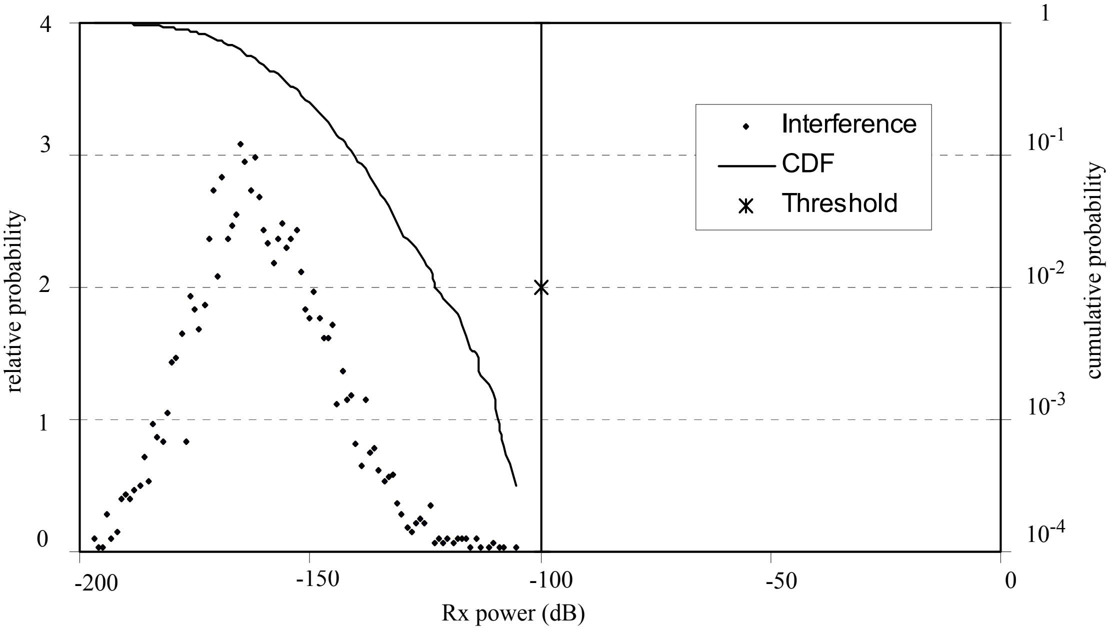

Figure C.10—Interference power profile from PTP to PMP SS (1 guard channel)

Annex D

(informative)

Additional material for FBWA systems in 2–11 GHz licensed bands

D.1 Sample 3.5 GHz psfd calculations

D.1.1 Thresholds

Using the same expressions detailed in B.2, assuming an operating frequency of 3.5 GHz (λ = 0.09 m), a noise figure of 5 dB and a typical BS antenna gain of 15 dBi, then the tolerable interference levels are given as: follows

PMP BS:

$$psfd_{\mathrm{BS}} = -145 - 10\mathrm{Log}(0.09^2) - 15 + 10\ \mathrm{Log}(4\pi) = -128\ \mathrm{dB[(W/m^2)/MHz]} \qquad \text{(D.1)}$$

D.1.2 PMP BS into victim PMP SS

A sample calculation is given below to determine the feasibility of meeting the psfd limit between a BS transmitter and PMP SS victim receiver. The formula for psfd is given as Eq. B.3 in B.2.1

Assuming
P_{Tx} is transmitter power (–10 dBW in 1 MHz),
G_{Tx} is transmitter antenna gain in the direction of the victim receiver (15 dBi),
R is range (80 000 m),
A_{losses} is atmospheric losses, ~0.01 dB/km.

Using the radio horizon range of 80 km from above, the psfd at the victim BS Rx antenna is as follows:

$$psfd_{\ \mathrm{victim}} = -15 + 18 - 10\log(4\pi) - 20\log(80\ 000) - (80)(0.01) = -105\ \mathrm{dB[(W/m^2)/MHz]} \qquad \text{(D.2)}$$

The interference level is well in excess of the objective for an $I/N = -6$ dB. Thus the horizon range of 80 km must be considered as a first-level trigger point, and satisfactory performance requires additional diffraction loss beyond the horizon. Note that the computation assumes LOS transmission across the full length of the interference path.

D.2 Description of calculations and simulation methods

D.2.1 Description of simulation parameters

For the Monte Carlo simulations subsequently described in D.2.6, typical FBWA transmission parameters were employed. Table D.1, the values of which vary partly from the initial assumptions in Table 22 and Table 23 (see 7.4.1), summarizes these parameters for both the 3.5 GHz and 10.5 GHz frequency bands. The simulation models assume a maximum cell radius of R = 7 km for both frequency bands. Link budget calculations indicated that, for this cell radius, a two-way link availability of 99.99% is achievable under LOS propagation conditions. The link budget estimates further indicated that at 3.5 GHz, an outbound transmission modulation index of 64-QAM could be supported and that an inbound modulation index of 16-QAM could be supported. Corresponding estimates for 10.5 GHz were 16-QAM outbound and 4-QAM inbound. For the three modulation indices, threshold *C*/*N* performance limits were assumed to be 12 dB, 18 dB, and 24 dB, respectively. C/I interference levels that would degrade threshold performance by 1 dB are 6 dB greater at 18 dB, 24 dB, and 30 dB.

Table D.1—Representative system and equipment parameters

Characteristics	**Frequency band**	
	3.5 GHz	**10.5 GHz**
Maximum cell radius	7 km	7 km
Channel bandwidth	7 MHz	5 MHz
Excess bandwidth	25 %	25 %
Nyquist bandwidth	5.6 MHz	4 MHz
SS Tx power	+21 dBm	+20 dBm
BS Tx power	+29.5 dBm	+26 dBm
SS antenna gain	+18 dBi	+25 dBi
BS antenna gain	+14.5 dBi	+16 dBi
Tx/Rx RF losses	3 dB at each end	3 dB at each end
Receiver noise figure	5 dB	5 dB
SS/BS antenna RPE	As specified in Garrison [B84]	As specified in Garrison [B85]
Link availability objective	99.99% @ BER = 10^{-6}	99.99% @ BER = 10^{-6}

As the available fade margin for all of the link options was identified to be modest, no clear sky cell edge ATPC was assumed. For simulations that involve shorter link distances, distance proportional ATPC was employed for inbound links. No ATPC was assumed for outbound links. At 10.5 GHz, relative rain attenuation between interference and victim links may be an issue. The computational procedure for estimation of this differential is described in D.2.6.1 as well as in Garrison [B77] and [B75]. ITU-R rain regions K and P were examined in the simulations.

For identification of the necessary CoCh coordination distance required by operators across a service area boundary, it is desirable to estimate the horizon distance. Estimates of the horizon distance for a spherical earth, and the diffraction loss beyond it, are summarized in D.2.2.1 and are detailed in Garrison [B78]. To identify the necessary AdjCh coordination distance and guard bands required by operators who have deployed in the same area, it is necessary to specify the NFD. This is the transmission cascade of the interference signal out-of-band emissions and the receiver filtering of the victim link. For the simulations, a first AdjCh NFD of 27 dB and a second AdjCh NFD of 49 dB were assumed.

To estimate interference levels, the discrimination provided by antenna RPE patterns is required. The simulations assumed the RPE patterns detailed in Garrison [B84] for 3.5 GHz and the RPE patterns detailed in Garrison [B85] for 10.5 GHz.

D.2.2 Adjacent-area/same-frequency case

These Monte Carlo simulations examined CoCh interference sensitivity across a service area boundary. The simulations assumed an uncoordinated alignment of interference and victim sectors. In accordance with the coordination criteria common to many regulatory agencies, interference sensitivity is expressed in terms of psfd as defined by dBW/m^2 in any 1 MHz. The critical value for psfd is set to be an $I/N = –6$ dB. This is a value that would degrade the receiver performance threshold by 1 dB. Critical pfd values vary with frequency and with the assumptions set for the link parameters. These values are detailed in the reference documents.

In addition to the LOS/diffraction loss assumptions, simulations were performed assuming a path loss exponent of 4 beyond 7 km. By selecting this model, excess path loss is maximized, thus resulting in a minimum coordination distance. This minimum distance was used only for best-case illustrative purposes. The coordination distances in the recommendations are based on the LOS plus excess diffraction loss model (normally horizon distance).

D.2.2.1 Horizon distance and diffraction loss

For the boundary CoCh pfd simulation estimates in D.2.2.3 and D.2.4.2, it was found necessary to evoke a horizon distance limit for many interference scenarios. To place the horizon distance into perspective, Table D.2 through Table D.9 estimate the excess diffraction loss to be expected from a spherical earth for interference link distances of 30 km, 60 km, 70 km, and 80 km. The table entries are parameterized against the relative elevations of the link antennas. Table entries of 0 indicate that the link has become LOS.

For specific link analysis, actual terrain data are required. The spherical earth assumption employed represents a worst-case estimate. The computational analysis is detailed in Garrison [B76] and is based on the procedures given in ITU-R Recommendation P.526.7 (2001-02) [B42].

Table D.2 and Table D.3 define diffraction loss estimates for a quite modest separation distance of D_i = 30 km. While it is quite unlikely that this distance would ever be considered as an appropriate horizon distance, the purpose of these two tables is to highlight the fact that, when D_i is small, LOS transmission may result, even for quite low relative antenna elevations.

Table D.2—Spherical earth diffraction loss at 3.5 GHz (D_i = 30 km)

Height of Radio 2 (m)	Height of Radio 1 (m)								
	10	20	30	40	50	60	70	80	90
10	24	16	10	5	0.5	0	0	0	0
20	16	7.5	1	0	0	0	0	0	0
30	10	1	0	0	0	0	0	0	0
40	5	0	0	0	0	0	0	0	0
50	0.5	0	0	0	0	0	0	0	0

Table D.3—Spherical earth diffraction loss at 10.5 GHz (D_i = 30 km)

Height of Radio 2 (m)	Height of Radio 1 (m)								
	10	20	30	40	50	60	70	80	90
10	23.5	12	4	0	0	0	0	0	0
20	12	1	0	0	0	0	0	0	0
30	4	0	0	0	0	0	0	0	0

Table D.4—Spherical earth diffraction loss at 3.5 GHz (D_i = 60 km)

Height of Radio 2 (m)	Height of Radio 1 (m)								
	10	20	30	40	50	60	70	80	90
10	63.5	55	49	44	40	36	32.5	29	26
20	55	47	40.5	35.5	31.5	27.5	24	21	18
30	49	40.5	34.5	29.5	25	21.5	18	14.5	11.5
40	44	35.5	29.5	24.5	20.5	16.5	13	10	6.5
50	40	31.5	25	20.5	16	12	8.5	5.5	2.5
60	36	27.5	21.5	16.5	12	8.5	5	1.5	0
70	32.5	24	18	13	8.5	5	1.5	0	0
80	29	21	14.5	10	5.5	1.5	0	0	0
90	26	18	11.5	6.5	2.5	0	0	0	0

Table D.5—Spherical earth diffraction loss at 3.5 GHz (D_i = 70 km)

Height of Radio 2 (m)	Height of Radio 1 (m)								
	10	20	30	40	50	60	70	80	90
10	77	68.5	62.5	57.5	53.5	49.5	46	42.5	39.5
20	68.5	60.5	54	49	45	41	37.5	34.5	31
30	62.5	54	48	43	39	35	31.5	28	25
40	57.5	49	43	38	34	30	26.5	23	20
50	53.5	45	39	34	29.5	25.5	22	19	16
60	49.5	41	35	30	25.5	22	18.5	15	12
70	46	37.5	31.5	26.5	22	18.5	15	11.5	8.5
80	42.5	34.5	28	23	19	15	11.5	8.5	5
90	39.5	31	25	20	16	12	8.5	5	2

Table D.6—Spherical earth diffraction loss at 3.5 GHz (D_i = 80 km)

Height of Radio 2 (m)	Height of Radio 1 (m)								
	10	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**
10	90.5	82	76	71	67	63	59.5	56	53
20	82	74	67.5	62.5	58.5	54.5	51	47	44.5
30	76	67.5	61.5	56.5	52.5	48.5	45	41.5	38.5
40	71	62.5	56.5	51.5	47.5	43.5	40	36.5	33.5
50	67	58.5	52.5	47.5	43	39	35.5	32.5	29.5
60	63	54.5	48.5	43.5	39	35.5	32	28.5	25.5
70	59.5	51	45	40	35.5	32	28.5	25	22
80	56	47	41.5	36.5	32.5	28.5	25	22	18.5
90	53	44.5	38.5	33.5	29.5	25.5	22	18.5	15.5

Table D.7—Spherical earth diffraction loss at 10.5 GHz (D_i = 60 km)

Height of Radio 2 (m)	Height of Radio 1 (m)								
	10	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**
10	81.5	70.5	62	55	49	43.5	38.5	34	29.5
20	70.5	59	51	44	38	32.5	27.5	22.5	18
30	62	51	42.5	35.5	29.5	24	19	14.5	10
40	55	44	35.5	28.5	22.5	17	12	7.5	3
50	49	38	29.5	22.5	16.5	11	6	1.5	0
60	43.5	32.5	24	17	11	5.5	.5	0	0
70	38.5	27.5	19	12	6	.5	0	0	0
80	34	22.5	14.5	7.5	1.5	0	0	0	0
90	29.5	18	10	3	0	0	0	0	0

Table D.8—Spherical earth diffraction loss at 10.5 GHz (D_i = 70 km)

Height of Radio 2 (m)	Height of Radio 1 (m)								
	10	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**
10	101.5	90	82	75	69	63.5	58.5	53.5	49
20	90	79	70.5	63.5	57.5	52	47	42.5	38
30	82	70.5	62	55.5	49	44	38.5	34	29.5
40	75	63.5	55.5	48.5	42.5	37	32	27	22.5

Table D.8—Spherical earth diffraction loss at 10.5 GHz (D_i = 70 km) *(continued)*

Height of Radio 2 (m)	Height of Radio 1 (m)								
	10	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**
50	69	57.5	49	42.5	36.5	31	25.5	21	16.5
60	63.5	52	44	37	31	25.5	20.5	15.5	11
70	58.5	47	38.5	32	25.5	20.5	15	10.5	6
80	53.5	42.5	34	27	21	15.5	10.5	6	1.5
90	49	38	29.5	22.5	16.5	11	6	1.5	0

Table D.9—Spherical earth diffraction loss at 10.5 GHz (D_i = 80 km)

Height of Radio 2 (m)	Height of Radio 1 (m)								
	10	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**
10	121	110	101.5	94.5	88.5	83	78	73.5	69
20	110	98.5	90.5	83.5	77.5	72	67	62	57.5
30	101.5	90.5	82	75	69	63.5	58.5	54	49.5
40	94.5	83.5	75	68	62	56.5	51.5	47	42.5
50	88.5	77.5	69	62	56	50.5	45.5	40	36.6
60	83	72	63.5	56.5	50.5	45	40	35.5	31
70	78	67	58.5	51.5	45.5	40	35	30.5	26
80	73.5	62	54	47	40	35.5	30.5	25.5	21.5
90	69	57.5	49.5	42.5	36.5	31	26	21.5	17

D.2.2.2 Outbound BS-to-SS interference

Figure D.1 illustrates the simulation model. Both interference and victim sectors are independently spun in 5° increments. For each spin, the most severe interference level is selected from 20 randomly located cell edge SS locations and entered into a database. A simulation run thus consists of 72 × 72 = 5184 pfd estimates that are sorted and presented as a CDF as a function of separation distance *D*. For any one spin combination, boresight BS sector angles are set by α and β. Interference distance D_i is set by *D* and the geometry. Interference RPE discrimination angles are set by θ and φ. The assignment of victim links to cell edge represents a worst-case estimate as these links experience the minimum outbound signal level.

D.2.2.3 Simulation results

Details of the simulation results for 3.5 GHz are described in Garrison [B79] and for 10.5 GHz in Garrison [B86]. While the critical pfd values that correspond to an $I/N = -6$ dB differ for the two frequency bands, the simulation conclusions are comparable. For LOS interference vectors, both simulation estimates indicated that between 15% to 20% of uncoordinated deployments would experience pfd exposures that exceed the objectives. This would occur for all distances *D* up to the horizon distance of approximately 80 km.

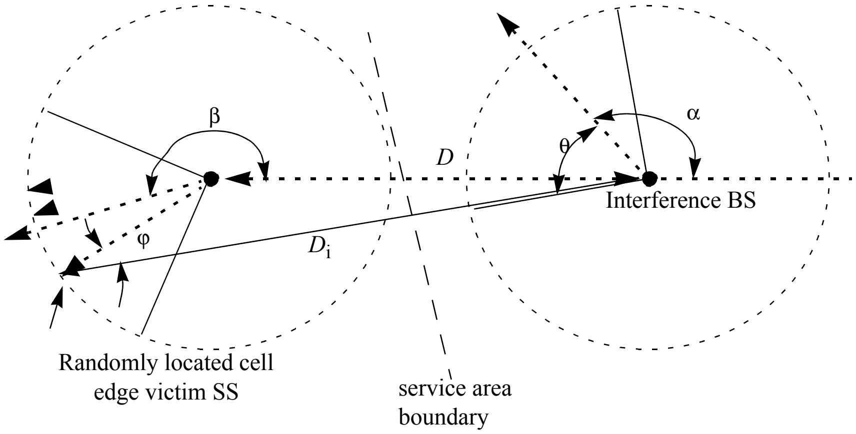

Figure D.1—Boundary BS-to-SS interference geometry

Additional simulation estimates examined the case for a path loss exponent of 4 for interference link distances greater than 7 km. For this scenario, the coordination distance could be reduced to 60 km. However, this propagation environment cannot be assured.

D.2.3 Inbound SS-to-BS interference

D.2.3.1 Simulation model

The simulation model for the inbound case is essentially the same as that of Figure D.1, except that the roles of the interference and victim vectors are reversed. The interference link is now a randomly positioned cell edge SS. When the SS is positioned at cell edge, the transmit power of the SS is maximized, thus this represents the most severe location for interference generation.

The victim is now an inbound SS-to-BS link. As distance proportional ATPC is applied to all inbound links, all such links would experience the same received signal level. Thus, the simulation is required to consider only one such link.

D.2.3.2 Simulation results

Details of the simulation results for 3.5 GHz are described in Garrison [B84] and for 10.5 GHz in Garrison [B85]. As in the preceding outbound case, pfd levels were found to be excessive up to the horizon distance assumption of 80 km. For both frequency bands, between 10% to 15% of uncoordinated deployments were found to exceed the *I*/*N* objective of –6 dB.

Again, the simulation results indicated that if interference links could be expected to experience excess path loss, then the coordination distance could be reduced. For the inbound interference cases, this was identified to be approximately 40 km. However, again, this propagation scenario cannot be assured.

D.2.4 BS-to-BS interference

D.2.4.1 Simulation model

Figure D.2 illustrates the simulation system model. It illustrates an uncoordinated alignment of interference and victim CoCh sectors, but one for which both sectors illuminate each other within their primary sector beamwidth. An inbound victim link is also illustrated. It is placed at cell edge. Distance proportional ATPC would place all victim links at the same received signal level. Thus, it is necessary to consider one such link with reference to critical pfd levels.

The interference separation distance D_i is simply D, the distance between the two BS locations. For any one interference estimate, angles β and θ set the RPE discrimination of the sector antennas.

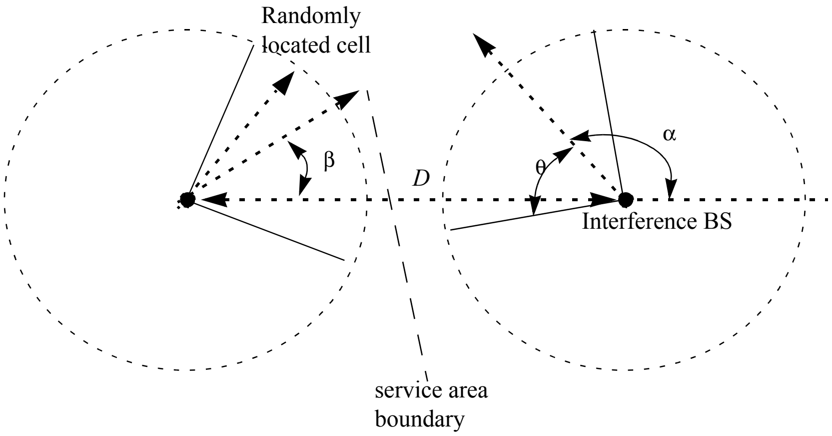

Figure D.2—Boundary BS-to-BS interference geometry

D.2.4.2 Simulation results

Details of the simulation results for 3.5 GHz are described in Garrison [B80] and for 10.5 GHz in Garrison [B86]. As both interference and victim antennas are wide beamwidth in 90° sectors, it would be expected that there would be a high probability of occurrence for worst-case couplings. The simulations confirmed this assumption. For LOS couplings, the simulations indicated that the pfd objectives would be exceeded in 23% of cases up to the assumed horizon distance of $D_i = 80$ km.

The problem becomes manageable if excess path loss or horizon diffraction losses such as those described in D.2.2.1 can be assumed. This would apply except for cases where both BS antennas are extremely high and exceed 70 m.

D.2.5 SS-to-SS interference

D.2.5.1 Analysis model and conclusions

The geometrical relationships for SS to SS interference are illustrated on Figure D.3. This scenario was not subjected to simulation as it was concluded that the probability of serious exposures was very low. The reasoning is as follows:

Most SS elevations are likely to be at a low elevation. This increases the probability that the interference path would experience excess path loss.

Low SS elevations reduce the horizon distance and increase the likelihood of diffraction loss. For example, if both SS antennas are at an elevation of 30 m, then for D_{i} = 60 km. Table D.4 and Table D.7 indicate that the diffraction loss would be 34.5 dB and 42.5 dB for the two frequency bands.

Both interference and victim antennas are narrow beamwidth. Hence, almost boresight alignments of both are required in order to create a worst-case interference conflict. For such alignments angle φ is quite small, and most of the RPE discrimination is set by angle θ. For 10.5 GHz, RPE discrimination is greater than 20 dB for θ larger than 5.5°. RPE discrimination is less at 3.5 GHz due to the wider beamwidth SS antenna. It requires θ to be larger than 13° in order to achieve 10 dB of discrimination.

There is no ATPC on the outbound link. Hence, a victim BS link located at a distance less than cell edge will experience received signal levels in excess of the link margin requirements. Conversely, distance proportional ATPC is assumed for the inbound link. Thus, an interference SS located at a distance less than cell edge will experience a reduction in Tx power, again favoring the victim link.

Full or partial time alignment is required between the active-data segments of the interference TDMA frame and the victim TDM frame.

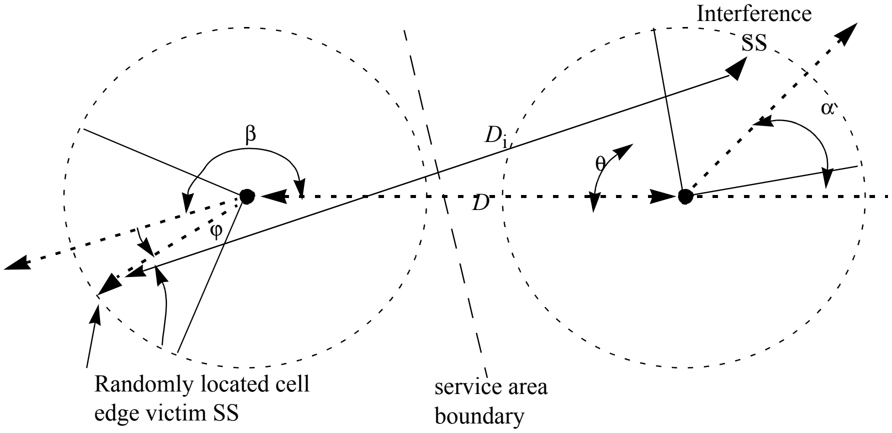

Figure D.3—Boundary SS-to-SS interference geometry

D.2.6 Same-area/adjacent-frequency case

When multiple system operators deploy on adjacent carriers in the same geographical area, the possibility of experiencing excessive interference can occur. This is a direct result of the finite emission limits of an interference transmitter for energy that falls in adjacent frequency channels. NFD sets the protection limits of a victim receiver. NFD is simply the cascade of the undesired signal spectra with the victim receiver filter.

The probability of experiencing excessive interference is dependent, in part, by the separation distance *S* of the victim BS location from that of the interference BS and, additionally; relative BS antenna orientation. As interference emissions usually continue to diminish with increasing frequency offset, frequency guard bands between operators offer an interference mitigation technique. Alternative interference techniques, such as cross-polarized operation of flanking carriers can also be considered.

Using Monte Carlo simulation techniques, these studies examined the preceding scenario. CDF estimates are developed that identify the probability of victim links experiencing excessive interference levels.

Figure D.4 illustrates a simple frequency reuse plan where each operator employs only two frequencies and two polarizations (vertical and horizontal). As illustrated, the closest carriers are shown to have the same polarization. This is a worst-case scenario. The guard channel C may or may not exist. Its need is to be determined as a conclusion of the simulations.

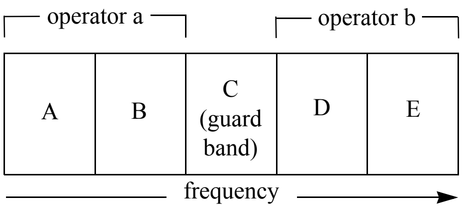

Figure D.4—Illustrative multiple operator frequency assignments

Figure D.5 illustrates a generic simulation model. As illustrated, BS-b is overlaid within the same sector of BS-a. It is positioned at some parameterized distance *S* from BS-a. For any one set of simulation estimates, the relative position of BS-b on the arc defined by *S* is assumed to be random, and hence this is specified within the simulation.

As the relative alignment of the BS-a and BS-b sectors is unknown, the simulations shift the relative boresight position of BS-b in 5° increments. Thus, one complete simulation involves 72 increments. To establish statistical significance, a number of randomly positioned SS locations are established. Simulation sensitivity analysis has identified that no more than 20 assignments are required. These locations are randomly reassigned for each BS-b increment shift. The SS locations are constrained to be randomly located are distance biased on an area-proportional basis. Generally speaking, it is only necessary to develop one set of 20 SS locations, either for interference or victim link assignments. The choice is dependent on the interference scenario under examination.

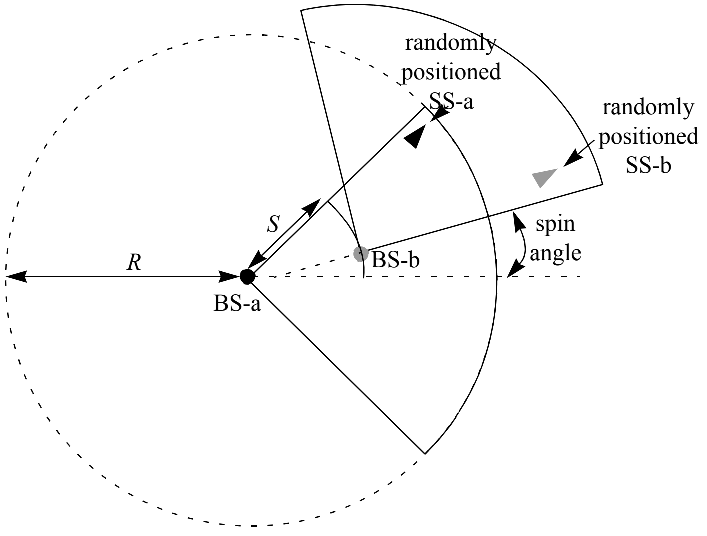

Figure D.5—Generic same-area simulation model

D.2.6.1 Rain attenuation computational procedure

At 3.5 GHz, propagation attenuation due to rain is essentially negligible. This is also essentially true at 10.5 GHz for short links in regions where the probability of intense rain rates is small. However, there are rain rate regions where 10.5 GHz rain propagation attenuation may be of significance, even for short paths. At issue here are the relative rain attenuation differential that results between an interference link and a victim link and the impact it may have on *C*/*I* performance.

In order to address these issues, a simplified method for estimating rain loss has been developed as detailed in Garrison [B75] and [B77]. The procedure is illustrated in Figure D.6. As before, a second BS is positioned within the sector at some parameterized distance *S* and at some random angle θ. Overlaid on the clear sky simulation model is a circular rain cell of radius R_c. As proposed in ITU-R Recommendation P.452 (2001-02) [B38], the radius of the cell is approximately 1.2 km and, for a first approximation, the rain rate is uniform within the cell. For any one set of simulation computations, the rain cell is randomly positioned at some central distance D_{rc} and angle γ.

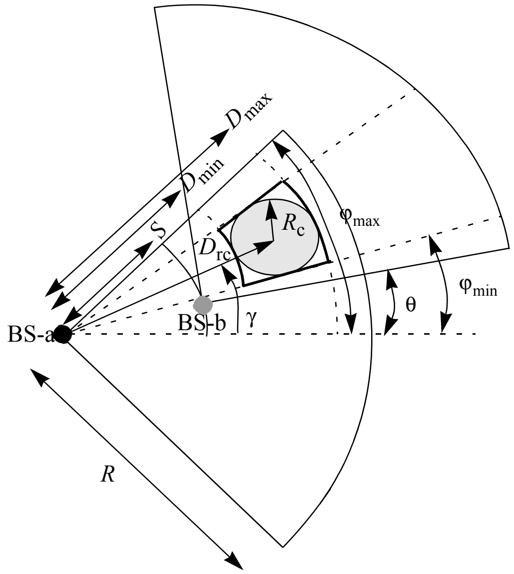

Figure D.6—Rain attenuation model

The location of the rain cell is constrained so that the full diameter of the cell is within the victim sector. Hence, for a number of randomly positioned victim links, it is highly likely that at least one such link experiences the maximum attenuation of the rain cell. The maximum attenuation is set by the ITU-R rain region and the specified link availability requirements ITU-R Recommendation P.530-10 (2001-11) [B43]. A link availability of 99.99 % was set for the simulations. The simulations examined ITU-R rain regions K and P. The respective fade margin requirements are 7 dB and 16 dB for these two regions.

To simplify the estimation of relative rain attenuation, the simulation assumptions for the area having a uniform rain rate were altered to be the area enclosed in bold on Figure D.6. This area is defined by the tangential intersections of both distance and angle to the edges of the rain cell. This allows the identification of inclusion distances (D_{max}/D_{min}) and inclusion angles ($\varphi_{max}/\varphi_{min}$) for rain loss estimates. To illustrate, consider the case for inbound SS-to-BS interference:

- If the victim and/or interference vectors fall outside the exclusion angles, then the rain attenuation is set to 0.
- If the victim and/or interference distance vectors are less than $D_{\min}$, then the rain attenuation is set to 0.
- If the victim and/or interference distance vectors fall within the exclusion angles and are greater than $D_{\max}$, then the rain attenuation is set to the maximum value of fade margin *FM*.
- If the victim and/or interference distance vectors fall within the exclusion angles and are within the inclusion distances ($D_{\max}/D_{\min}$), then the rain attenuation is proportionally adjusted to the distance of the vectors within the rain area. For a vector distance of R_v, this would just be $(R_v - D_{\min}) \times FM/(2R_c)$.

Each same-area interference scenario invokes a somewhat different set of inclusion/exclusion criteria for relative rain loss estimates. See Garrison [B75] and [B77] for details.

D.2.6.2 Outbound same-area BS-to-SS interference

D.2.6.2.1 Simulation model

The simulation model specific to outbound BS-to-SS interference is illustrated in Figure D.5. With the interference BS located in the victim sector at distance *S*, 20 victim SS locations are assigned for each angular 5° spin. These SS locations are assumed to be randomly biased on an area-proportional basis. Consequently, 50% of the SS locations would be expected to be at a distance greater than 0.75*R*, *R* being the cell radius.

As the interference BS is, by definition, located within the victim sector, it is required only to spin the interference BS sector alignment. For each interference estimate, the impact of each of the four interference sectors is added. A composite simulation run thus consists of 1440 interference estimates. For each interference computation, the simulation *C*/*I* examines antenna RPE, NFD, distance differentials, and, if it applies, antenna XPD. Each time the sector alignment is incremented, all of the SS random parameters are adjusted based on a randomizing seed. For the 10.5 GHz simulations, this also applies to the positioning of the rain cell.

D.2.6.2.2 Simulation results

As previously discussed, link budget estimates concluded that outbound transmissions could support 64-QAM at 3.5 GHz and 16-QAM at 10.5 GHz. Hence, critical *C*/*I* values that impact performance threshold by 1 dB are correspondingly 30 dB and 24 dB. Details of the simulation results may be found in Garrison [B76] and [B83]. Simulation sensitivity estimates relative to BS separation distance *S* demonstrated that *C*/*I* performance is poorest when *S* is small, noticeably for $S < 0.5$ km. Subsequent discussions are thus focused on such distances.

For clear sky estimates, the *C*/*I* performance was found to be comparable for both frequency bands. For same-polarization operation without a guard band, NFD was set to 27 dB. CDF probabilities were found to increase rapidly at, or about, this *C*/*I* value.

At 3.5 GHz, and this NFD, the simulations indicated that from 1% to 7% of the exposures would exceed the 64-QAM performance threshold of 24 dB. The percentage exceeding the 1 dB *C*/*I* = 30 dB threshold impairment increased, were significantly greater, ranging between 15% to 50%.

At 10.5 GHz, only a fractional percentage of the clear sky exposures (< 0.5%) were found to exceed the 16-QAM performance threshold of 18 dB. Those exposures exceeding the 1 dB threshold *C*/*I* value of 24 dB were found to be less than 4%.

When the relative rain attenuation differential at 10.5 GHz was examined, the simulations indicated that, in rain region K, the performance threshold impairment increased to a maximum of 3% for $S = 0.1$ km and the 1 dB threshold impairment increased to 6% at the same distance. For rain region P, these values increased to 4% and 7%, respectively, for the two C/I limiting values.

However, the CDF versus C/I simulation estimates demonstrated a very sharp knee in the vicinity of the assumed NFD value of 27 dB. Except for rain region P, an improved NFD of 35 dB would move all the remaining scenarios to within acceptable performance objectives. Such an NFD improvement is likely reasonable for modern transmitters. For rain region K, threshold impairment at a C/I value of 18 dB and 1 dB impairment at a C/I value of 24 dB both improve to less than 1%.

For rain region P, the CDF knee was found to be less pronounced. Hence, modestly improved NFD was found to have a lesser impact. Here, the simulations indicated that a BS separation distance of 350 m to 500 m might also be required.

Interference mitigation techniques, such as cross-polarized frequency assignments or the specification of a guard band, would reduce the probabilities of critical C/I levels to negligible magnitudes. They enhance isolation to well more than would be required. The first mitigation technique involves operator coordination while the second is wasteful of bandwidth. Both techniques can be avoided if the stated NFD improvements are achievable.

D.2.6.3 Inbound same-area SS-to-BS interference

D.2.6.3.1 Simulation model

For inbound SS-to-BS interference, the generic simulation model of Figure D.5 is appropriate. The choice as to which sector is deemed to be the victim and which sector is deemed to be associated with interference is arbitrary.

For the clear sky cases, the overlay sector/cell was set to be victim. As all victim links are assumed to employ distance-proportional ATPC, all victim links are expected to arrive at the victim BS at the same level of signal strength. Thus, the C/I estimates need to only consider the signal level of one cell-edge victim-SS–to–BS link. Twenty interference SS locations were assigned. These were positioned based on a random distance-biased/area-proportional basis. The transmit power of each was ATPC-adjusted in accordance with their relative distance from the interference BS. As with the outbound case, a simulation run consists of 1440 interference estimates.

For rain-faded C/I estimates at 10.5 GHz, it was found to be computationally convenient to consider the overlay sector as the source of interference. Assuming that the inbound multiple access method is TDMA, a randomly positioned cell-edge interference SS is selected to be actively transmitting. Twenty randomly positioned victim SS locations are assigned for each spin, and the clear sky C/I of each is computed. Signal levels C and interference levels I are adjusted in accordance with the rain attenuation methodology described in D.2.6.1. As the interference vectors are set to maximum power at cell edge, they require no ATPC adjustment. Each potential victim SS is ATPC-signal-level-adjusted in accordance with distance and rain attenuation. The ATPC adjustment is set to reestablish the cell-edge received-signal level. If this is not possible, then the Tx power of a victim SS is just set to maximum power level.

As previously discussed, inbound link budgets identified that 16-QAM could be supported at 3.5 GHz but that only 4-QAM could be supported at 10.5 GHz. This sets the respective inbound C/I threshold limits at 18 dB and 12 dB. The corresponding inbound 1 dB impairment C/I limits are thus 24 dB and 18 dB.

D.2.6.3.2 Simulation results

Except for differences in detail, inbound interference simulation results were found to be comparable to the outbound cases discussed in D.2.6.2.2. The inbound results are detailed in Garrison [B82]. Analysis has indicated that results at 10.5 GHz are comparable. Again, the CDF versus *C*/*I* estimates were found to have a sharp knee in the vicinity of the value set for NFD.

For 3.5 GHz, and an assumption of 16-QAM, it was found that only a very small fraction of exposures would exceed the performance threshold of 18 dB. At the 1 dB threshold impairment level of 24 dB, less than 4% of the exposures would exceed the requirement. As previously discussed, an improvement of NFD to 35 dB would essentially eliminate all interference problems, up to 16-QAM.

Referenced to 4-QAM, clear sky estimates at 10.5 GHz were found to be even more improved. There were no *C*/*I* estimates that exceeded the critical limiting values of 12 dB and 18 dB. This was found to be the case even for rain region K. However, in rain region P, it was again observed that the sharp CDF knee was lost. Between 1% and 2% of the exposures were found to exceed the performance limit of 12 dB and 3% to 6% to exceed the 1 dB threshold limit of 18 dB. NFD improvement to 35 dB would reduce the 1 dB impairment excedance to 1%.

D.2.6.4 Same-area BS-to-BS interference

D.2.6.4.1 Simulation model

The generic simulation model given by Figure D.5 and the rain attenuation estimation model given by Figure D.6 again apply. Inbound links are now victim so the assumed modulation indices are 16-QAM at 3.5 GHz and 4-QAM at 10.5 GHz. Simulation results for 3.5 GHz are detailed in Garrison [B81] and for 10.5 GHz in Garrison [B74].

As the inbound links employ ATPC, clear sky interference estimates need only to consider one cell-edge victim link. The simulation clear sky spin increment was set to 1°. A composite clear sky simulation run is thus represented by 360 *C*/*I* estimates.

For the rain-faded simulation estimates at 10.5 GHz, 20 distance-biased victim TS locations were set for a spin increment of 5°. To examine rain loss differential, the TS locations were randomly positioned in accordance with prior discussions. Rain-faded CDF estimates were thus based on 1440 *C*/*I* interference exposures.

D.2.6.4.2 Simulation results

As both interference and victim antennas are wide beamwidth, it would be expected that interference sensitivity would be significantly more severe than previously reported for the other scenarios. The simulations confirmed this to be the case.

For clear sky operation and same polarization operation without a guard band, interference exposures that exceed the performance objectives were found to range from 20% to 50%. These would not be resolvable unless excessively large separation distance limits were placed on the two BS sites (of the order of 3 km or greater). If operator coordination is possible, then it is likely that cross-polarized sector assignments would resolve the problems. Alternatively, a guard band could be considered, but this, of course, is wasteful of bandwidth. A much preferable solution would be to consider the use of ultra-linear BS transmitters that achieve NFD improvements equal to or greater than the previously noted mitigation techniques.

Similar arguments apply to rain-faded operation at 10.5 GHz. However, the simulation conclusions were more restrictive. NFD improvement up to that of a guard band (49 dB) is still insufficient to meet margin limits unless distance BS separation *S* is set to greater than 350 m. Operation in rain region P was found to be even more restrictive. For $S < 0.5$ km, there were no simulation estimates that would achieve 4-QAM performance limit objectives for an NFD of 49 dB. Consideration of linearized Tx power amplifiers that achieve emission suppression of –60 dBc in the first adjacent channel would resolve all of the aforementioned interference issues associated with BS-to-BS couplings.

D.2.6.5 Same-area SS-to-SS interference

D.2.6.5.1 Analysis model and conclusions

This interference mechanism was not simulated. The conclusions are comparable to those given in D.2.4.

D.3 Interference-mitigating effects of AAs

The probability of interference, but not necessarily the maximum value of interference, may be reduced if AAs are used at the BS. However, the coordination distance trigger does not change as a result of the use of AA.

Simulations were performed to model the coexistence at 3.5 GHz using AAs at the BS. The same parameters as in Table D.1 were used in the simulations except for the BS antenna gain and RPE, which are decribed in Arefi [B70].

D.3.1 Inbound SS-to-BS interference with AA at the BS

D.3.1.1 Simulation model

The geometry used for this analysis is shown in Figure D.7. The victim BS is assumed to use AA instead of 90° sector antennas, thus having a narrow beam pointing to a randomly changing direction at any point in time. It is assumed that all the interfering SS are at the cell edge and actively transmitting with their maximum power on the same carrier as the victim link within the given time slot. It is also assumed that only one of the SS at the cell edge is transmitting in the time slot of interest. The interference power from the interfering SS arriving at the victim BS is then calculated to form a snapshot of the interference power. The simulation was then repeated many times to reveal the likelihood of various interference levels through CDF plots.

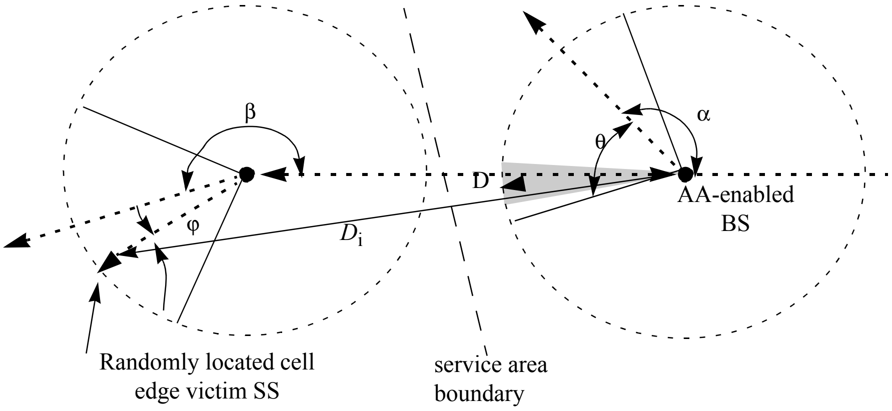

Figure D.7— AA simulation geometry

Adaptive beam-forming provides the capability of steering nulls towards a number of interferers. Such nulls are usually deeper than what has been assumed in the pattern described in Arefi [B70], thus further reducing the interference. This effect has not been included in this analysis.

D.3.1.2 Simulation results and discussion

Details of the simulation results in terms of likelihood of interference psd at the victim BS are presented in Arefi [B70]. It shows that the interference psd is lower than permissible value in about 99% of the time/cases for an intercell distance of 18.6 km for 16-QAM. The study shows that, with the utilization of AA, the occurrence of worst-case interference scenario due to main-beam–to–main-beam coupling between the victim and the interferer is limited to a very small percentage of time/cases. This interference is, however, more severe than the case with conventional antennas, and large separation distances are required to completely remove the interference altogether. However, with AA, these extreme cases happen only a small fraction of time and/or interference cases due to the statistical factor introduced by the randomness of the AA main beam orientation in time/space.