IEEE 802.16.2-00/01r9

Recommended Practice for Coexistence of Broadband Wireless Access Systems

Prepared by the 802.16.2 Task Group of the IEEE 802.16 Working Group on Broadband Wireless Access

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Introduction

This introduction provides some background on the rationale used to develop this recommended practice. This information is meant to aid in the understanding and usage of this recommended practice.

This recommended practice provides guidelines for minimizing interference in Broadband Wireless Access systems. Pertinent coexistence issues are addressed and recommended engineering practices provide guidance for system design, deployment, co-ordination and frequency usage. This document covers the 10 to 66 GHz frequencies in general, but is focused on the range of 23.5-43.5 GHz.

This recommended practice, if followed by manufacturers and operators, should allow a wide range of equipment to coexist in a shared environment with acceptable mutual interference.

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

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1 Overview

This document provides recommended practice for the design and coordinated deployment of Broadband Wireless Access (BWA) systems to control interference and promote coexistence. This recommended practice is divided into 8 sections. Section 1 provides the scope of the recommended practice. Section 2 lists references to other standards that are useful in applying this recommended practice. Section 3 provides definitions and acronyms that are either not found in other standards, or have been modified for use with this recommended practice. Section 4 provides an overview of BWA Systems including system architecture and medium overview. Section 5 deals with equipment design parameters including limits for both in-band and out-of-band BWA system emissions through parameters including radiated power, spectral masks and antenna patterns. Also included in Section 5 are recommended tolerance levels for certain receiver parameters, including noise floor degradation and blocking performance, for interference received from other BWA systems as well as from other systems. Section 6 provides the methodology to be used in the deployment and co-ordination of BWA systems including band plans, separation distances, and power spectral flux density limits to facilitate coordination and to enable successful deployment of BWA systems with tolerable interference.

1.1 Scope

The intent of this document is to define a set of consistent design and deployment recommendations, which promote coexistence for BWA systems. These recommendations, if followed by manufacturers and operators, will facilitate a wide range of equipment to coexist in a shared environment with acceptable mutual interference.

The scope of this practice includes the examination of interference between systems deployed across geographic boundaries in the same frequency blocks and systems deployed in the same geographic area in adjacent frequency blocks. This document emphasizes coexistence practices for Point-to-Multipoint systems. This practice does not cover coexistence issues due to intra-system frequency re-use within the operator's authorized band, and it does not consider the impact of interference created by BWA systems on non-BWA terrestrial and satellite systems.

In the event that local and/or ITU Radio Regulations have more stringent requirements than the recommendations contained within this document, then those regulations take precedence.

This document was developed based on input from IEEE 802.16.1, but is intended to be generally applicable to a wide range of broadband wireless systems.

2 References

This recommended practice shall be used in conjunction with the following publications.

IEEE 802.16.1, Telecommunications and Information Exchange Between Systems - LAN/MAN Specific Requirements - Air Interface for Fixed Broadband Wireless Access Systems.
< revision # to be specified before letter ballot>]

3 Definitions and Acronyms

For the purposes of this recommended practice, the following terms and definitions apply. IEEE Std 100-1992, The New IEEE Standard Dictionary of Electrical and Electronics Terms, should be referenced for terms not defined in this clause.

3.1 Definitions

3.1.1 authorized band

The range of frequency band, which a license holder is permitted to operate its radio transmitters and receivers.

3.1.2 base transceiver station

The assemblage of hardware including antenna(s), transmitters, receivers, modem functions, network functions, control functions, etc. at a geographic point within a BWA network which provides network access to multiple subscribers located within the service region of the base station in a PMP system.

3.1.3 broadband

Having instantaneous bandwidths greater than around 1 MHz and supporting data rates greater than 1.5 Mbps.

[std 100: broadband. In general, wide bandwidth equipment or systems that can carry signals occupying a large portion of the electromagnetic spectrum. A broadband communication system can simultaneously accommodate television, voice, data, and many other services.]

3.1.4 broadband wireless access

The delivery of broadband service between a BTS and STS using wireless technology.

3.1.5 cross-polar discrimination

The XPD is the difference in dB between the peak of the copolarized main beam and the maximum cross-polarized signal on the principal planes of the antenna. The principal planes are defined as an azimuth plane for zero degree elevation and an elevation plane at zero degree azimuth.

3.1.6 digital modulation

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The process by which some characteristics (frequency, phase, amplitude or combinations thereof) of a carrier frequency is varied in accordance with a digital signal. Digital modulation is characterized by discrete changes of state for the carrier signal rather than continuous changes as in analog modulation.

3.1.7 downlink

RF transmissions from the BTS to the STS

3.1.8 DS-3

A North American Common Carrier Multiplex level in a TDM system having a line rate of 44.736 Mbps.

3.1.9 frequency block

A portion of radio spectrum assigned to an operator. A frequency block would normally be considerably larger than any individual radio channel. This term is usually considered to be synonymous with authorized band.

3.1.10 frequency division duplex

A duplex scheme where transmission occurs simultaneously on the uplink and downlink path using different frequencies.

3.1.11 Frequency Range 1

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

3.1.12 Frequency Range 2

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

3.1.13 Frequency Range 3

For purposes of this document, Frequency Range 3 refers to 43.5 to 66 GHz

3.1.14 Frequency re-use

A technique for employing a set of frequencies multiple times within cells/sectors in close proximity.

3.1.15 frequency slot

The smallest element of a frequency band plan that can be aggregated to form a block assignment.

3.1.16 inter-cell link

Inter-cell links may use wireless, fiber, or copper facilities to interconnect two or more BTS/CS units.

3.1.17 multi-carrier system

The use of two or more carriers to provide service from a single transmitter.

3.1.18 multipoint

A wireless topology where a single base station provides service to multiple subscribers located within the coverage area of the base station, and the subscribers are in geographically different locations with respect to each other. The sharing of resources may occur in the time domain, frequency domain, or both.

3.1.19 OC-3

One hierarchical level in the Synchronous Optical Network (SONET) transmission standard. The line rate for this level is 155.52 Mbps.

3.1.20 occupied bandwidth

For a single carrier, it 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 multi-carrier transmission uses a common amplifier stage, the occupied bandwidth of this composite transmission is defined by the following relationship:
$B_{OM} = 1/2\ B_{OU} + 1/2\ B_{OL} + (F_{OU} - F_{OL})$
Where:
$B_{OM} = B_O$ of the multi-carrier system
$B_{OU} = B_O$ of the uppermost sub-carrier
$B_{OL} = B_O$ of the lowermost sub-carrier
F_{OU} = Centre frequency of the uppermost sub-carrier
F_{OL} = Centre frequency of the lowermost sub-carrier

NOTE: This multi-carrier definition will give a bandwidth which is slightly wider than the multi-carrier 99% power bandwidth e.g., for 6 identical, adjacent carriers, Bo will contain 99.5% of the first carrier, 99.5% of the last carrier and 100% of the four middle carriers = 99.8333% of power.

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

3.1.21 out-of-band 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 main emission.

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3.1.22 power control

A technique used in BWA systems to adaptively adjust the transmit power of a transmitter to maintain the received signal level within some desired range.

3.1.23 power flux density

The radiated power flux per unit area expressed as Watts/m^2.

3.1.24 power spectral flux density

The radiated power flux per unit bandwidth per unit area. It is often expressed in Watts/MHz/m^2.

3.1.25 Radiation Pattern Envelope

The RPE is a graph that represents the maximum sidelobe levels of an antenna at all frequencies over the entire band.

3.1.26 service areas

A geographic area for which BWA licenses are issued.

3.1.27 spectrum dis-aggregation

Some regulators allow a license holder to segregate their spectrum, to permit several operators access to sub-portions of the licensee’s authorized band.

3.1.28 spurious emissions

Emissions greater than 200% of the occupied bandwidth from the edge of the authorized bandwidth.

3.1.29 subscriber transceiver station

The assemblage of hardware including antenna(s), transmitters, receivers, modem functions, network functions, control functions, etc. at a geographic point within a BWA network which delivers and collects the wireless traffic from subscriber(s) and transfers it to the BTS within line of site.

3.1.30 time division duplex

A duplex scheme where uplink and downlink transmissions occur at different times while sharing the same frequency.

3.1.31 uplink

The transmission of information from the STS to BTS.

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3.1.32 unwanted emissions

Comprise out-of-band emissions, spurious emissions and harmonics.

3.1.33 virtual block edge

A reference frequency used as a block edge frequency for testing of unwanted emissions, so as to avoid effects of RF block filters.

3.2 Acronyms

AZ	Azimuth
BRAN	Broadband Radio Access Network
BTS	Base Transceiver Station
BW	Bandwidth
BWA	Broadband Wireless Access
CEP	Conférence Européen des Administrations des Portes et des Télécommunications (European Conférence of Postal and Télécommunication Administrations)
C/I	Carrier to Interference ratio
C/N	Carrier to Noise ratio
COFDM	Coherent Orthogonal Frequency Division Multiplex
COPOL	Co-polarized
CROSSPOL	Cross-polarized
CS	Central Station
CW	Carrier Wave
DRS	Data Relay Satellite
EL	Elevation
EIRP	Effective Isotropic Radiated Power
EIRPSD	Effective Isotropic Radiated Power Spectral Density
EN	European Norm
ERC	European Radiocommunication Committees
ETSI	European Telecommunications Standards Institute
FDD	Frequency Division Duplex
FDMA	Frequency Division Multiple Access
GSO	Geostationary Orbit
IF	Intermediate Frequency
IL	Inter-cell Links
IILS	Inband Inter-cell Link Station
ITU	International Telecommunication Union
LMCS	Local Multipoint Communication System
LMDS	Local Multipoint Distribution Service
LOS	Line of Sight
MAC	Medium Access Control

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MP	Multipoint
MP-MP	Multipoint-to-Multipoint
MVDS	Multipoint Video Distribution System
MWS	Multimedia Wireless Systems
OFDM	Orthogonal Frequency Division Multiplexing
OOB	Out-Of-Band
OMT	Ortho Mode Transducer
PIM	Passive Intermodulation
PLL	Phased Locked Loop
PMP	Point-to-Multipoint
ppm	Part per Million (10^{-6})
PSFD	Power Spectral Flux Density
PSD	Power Spectral Density
PTP	Point-to-Point
RF	Radio Frequency
RPE	Radiation Pattern Envelopes
RX	Receive
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Key
RPE	Radiation Pattern Envelopes
RPT	Repeater Station
STS	Subscriber Transceiver Station
TDD	Time Division Duplex
TDM	Time Division Multiplexing
TDMA	Time Division Multiple Access
TE	Terminal Equipment
TX	Transmit
VSWR	Voltage Standing Wave Ratio
XPD	Cross Polar Discrimination
XPI	Cross Polar Isolation

4 Summary of BWA Practice Recommendations

4.1 Document Philosophy

Electromagnetic waves respect the same geographic and spectral boundaries, which are used by regulators for making assignments to BWA operators. In the real world, radio waves permeate through legislated (and even national) boundaries and emissions spill outside spectrum allocations. These two facts conspire to make coexistence issues between multiple operators inevitable.
There are also EMI issues based on natural phenomena (e.g. lightning) and man made EMI, which consists of intentional (e.g., RF transmitters) and unintentional (e.g., radiated spurious) sources (e.g. PCS and cellular phones), which is addressed in Section 0.

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Resolving coexistence issues is a prerequisite for achieving a sustainable BWA industry. The following Recommendations are provided for consideration by operators, manufacturers and administrations, which we believe, will promote coexistence. In reviewing these Recommendations, it should be understood that this document contains no concept of coexistence “protection.” That is because, during the document’s preparation, there emerged no single set of Recommendations that guaranteed coexistence without squandering either spectrum or the opportunity for economical deployments. Moreover, it would not contribute to fostering a BWA industry to suggest rules, which might inhibit either innovation or aggression in deployments. In support of this view, this document does not find it appropriate to make recommendations, which touch on intra-system matters such as frequency plans, frequency reuse patterns, etc. The consequence of these decisions is that coexistence, then, becomes as much a state of mind as it is a technological activity, relying heavily on the good-faith collaboration between spectrum holders for economical solutions to be implemented.

The document analyzes coexistence using two scenarios:
-A Co-channel (CoCh) scenario in which two operators are in either adjacent territories or territories within radio line of sight of each other and have the same spectrum allocation, and
-An Adjacent Channel (AdjCh) scenario in which the licensed territory of two operators overlaps and they are assigned adjacent spectrum allocations.

It must be realized that separating coexistence issues to these two scenarios is just an analytical convenience. In an actual deployment, one should expect coexistence issues to arise simultaneously from both scenarios as well as from multiple operators having the same scenario. Section 9 provides a toolkit of interference mitigation measures, which can be utilized [marshaled] to solve coexistence problems. Because of the wide variation in the geometric distribution of users/base stations, of radio emitter/receiver parameters, of localized rain patterns and the statistics of overlapping emissions in frequency and time, it is impossible to prescribe in this document which mitigation measures are appropriate to resolving a particular coexistence challenge. In the application of these mitigation measures, there should be a bias toward isolating individual terminals or groups of terminals for modification rather than the imposition of pervasive restrictions.

Following are the specific recommendations:

Recommendation 1: Adopt a “6 dB below receiver thermal noise in the victim receiver criterion” as being a value of interference from each interfering operator, which is “acceptable.” The document recommends this value in recognition of the fact that it is not practical to insist upon an “interference-free” environment. Having once adopted this value, there are some important consequences:
Each operator acknowledges that he is willing to accept a 1 dB degradation in his receiver sensitivity from each other operator. In some regard, the –6 dB value becomes the definition of “coexistence.”
Depending upon the particular deployment environment, an operator may have a –6 dB contribution from multiple CoCh and AdjCh operators. Each operator should include design

margin in his system which is capable of simultaneously accepting the compound effect of interference from all other relevant operators, each at the –6 dB level.
The design margin in (b) above 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, which 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 acknowledge claims of interference even if the particular prediction method which was used to substantiate the –6 dB value suggests that there should not be any.

Recommendation 2: Each operator should take the initiative to collaborate with other known operators prior to initial deployment and at every relevant system modification. This recommendation should be followed even if an operator is the first to actually deploy in a region. To encourage this behavior, the document introduces the concept of using power spectral flux density values to "trigger" different levels of initiatives taken by an operator to give notification to other operators. The specific trigger values and their application to the two deployment scenarios are discussed in Recommendations 5 and 6 below and in Section 7. In some regulatory environments, the fact that the "triggers" were properly analyzed and that the proper cooperative initiative was made can be used as evidence of operating in good faith to promote coexistence.

Recommendation 3: Each operator should design and deploy his own system for the maximum amount of frequency reuse (i.e. use the frequencies uniformly across the allocated band). The logic behind this Recommendation is that the same techniques of base station site selection, antenna pattern management and emission control that must be employed to facilitate aggressive frequency reuse within a system will contribute to its coexistence with other systems. Recommendations 9,10 and 11 below and in Section 6 provide recommended minimum antenna patterns, spectral masks and maximum EIRP from the vantage point of coexistence. These do not, however, guarantee coexistence. Even the most dense frequency reuse system does not guarantee coexistence. However, starting from a foundation of a "better" engineered system can facilitate the later resolution of coexistence issues.

Recommendation 4: In the resolution of coexistence issues, incumbents/first movers should have the same status as operators who deploy at a later time. The logic behind this Recommendation is that some coexistence problems cannot be resolved simply by modifications to 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 the overlapping territories means the incumbent and the late-comer may be competing for the same clients. The reality of some spectrum allocations are such that AdjCh operators will be allocated side-by-side frequency channels. As is seen below, this is an especially difficult coexistence problem to resolve without co-location of the operator's cell sites. In resolving coexistence issues, it is legitimate to weigh the capital investment an incumbent operator has made in his system. However, for the BWA industry to succeed, the incumbent must be willing to share relevant parameters about his system and to constructively participate in the application of interference mitigation measures.

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Recommendation 5: No coordination is needed in a given direction if the transmitter is greater than 60km from either the service area boundary or the neighbor's boundary (if known) in that direction.

Recommendation 6: Recommendation 2 above introduced the concept of using power spectral flux density "triggers" as a stimulus for an operator to take certain initiatives to collaborate with his neighbor. The coordination trigger values (see Annex B -) of –114 dBW/MHz/m^2 (24,26,28GHz bands) and -111dBW/MHz/m^2 (38,42GHz bands) are employed in this document in the initiative procedure described in Recommendation 7 below. These values were derived as that power spectral flux density values which, if present at an average base station antenna and average receiver, would result in approximately the –6 dB interference value cited in Recommendation 1. It should be emphasized that the trigger values are useful only as thresholds for taking certain actions with other operators; they do not make an absolute statement as to whether there is, or is not, interference potential. Where administrations have permitted significant deployment of point-to-point links as well as point-to-multipoint systems, different psfd trigger levels may be appropriate (e.g. –125 dBW/MHz/m^2 at 38 GHz band is applied in Canada to protect point-to-point links).

Recommendation 7: Apply the "triggers" of Recommendations 5 and 6 prior to deployment and prior to each relevant system modification. Should the trigger values be exceeded, then the operator should try to modify the deployment to meet the trigger, and failing which the operator should coordinate with the affected operator. Three existing coordination procedures are described in the Annex <xx>.

Recommendation 8: For same area /adjacent channel interference cases, deployment will usually need one guard channel between nearby transmitters. Where the transmissions are of different bandwidth, the guard channel should be equal to the wider channel. Where administrations do not set aside guard channels, the affected operators will need to reach agreement on how the guard channel is apportioned between them. In some special cases, careful and intelligent frequency planning and/or use of orthogonal polarization may permit some use of this guard channel.

Recommendation 9: Utilize antennas for the base station and subscriber terminals at least as good as shown in Section 6.2. The coexistence simulations which led to the Recommendations contained herein revealed that most coexistence problems are the result of main-beam interference. The side lobe levels of the Base Station antennas are of a significant, but secondary influence. The sidelobe levels of the subscriber antenna are of tertiary importance. In the context of coexistence, therefore, antennas, such as those presented in Section 6.2 are sufficient. It should be emphasized that utilizing antennas with sidelobe (and polarization) performance better than the minimum will not degrade the coexistence performance and, in fact, are an effective mitigation technique for specific instances. In many cases, intra-system considerations will place higher demands on antenna performance than those required for inter-system coordination.

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Recommendation 10: Utilize an emissions mask at least as good as provided in Section 6.1.4. The utility of emissions masks for controlling adjacent channel coexistence issues is strongly dependent upon the separation of the two emitters in space and in frequency. In the case where there is large spatial separation between emitters, the opportunity exists for an interfering emitter to be much closer to a receiver than the desired emitter. This unfavorable range differential can overwhelm even the best emissions mask. Likewise, emissions masks are most effective when at least 1 guard channel exists between allocations. The emissions mask presented in Section 6.1.4 is most appropriate for the case where there is one guard channel between allocations and a modest separation of emitters. For cases where there no guard band is provided, it is recommended that co-location of emitters be considered before trying to improve emissions masks.

Recommendation 11: Utilize maximum EIRP and Subscriber Power control in accordance with Section 6.1.1 and 6.1.2, respectively. The interests of coexistence are served by reducing the amount of EIRP emitted by base station, subscriber and repeater terminals. The recommended maximum EIRP spectral density values are significantly less than allowed by some regulatory agencies but are believed to be an appropriate balance between constructing robust BWA systems and promoting coexistence.

Recommendation 12: In conducting analyses to predict power spectral flux density and for coordination purposes, incorporate the following considerations:

- Path loss to a point on the border
  - Clear air (no rain) plus relevant atmospheric absorption
  - Intervening terrain blockage
- For the purpose of calculating psfd trigger compliance level, the psfd level at the service area boundary should be the maximum value which occurs at some elevation point up to 500 m above local terrain elevation.
- The actual electrical parameters (e.g., EIRP, antenna patterns, etc.)
- Where possible, use established ITU-R Recommendations relating to propagation and rain fading statistics (e.g. ITU-R P. 452).

4.2 Guidelines for geographical and frequency spacing

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

The two main deployment scenarios are as follows:

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

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The most severe of the several mechanisms that apply to each case determines the guideline spacing, as follows:

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

Dominant interference path (note 1)	Scenario	Spacing for acceptable Performance
PMP Hub to PMP hub	Adjacent Area, same frequency	[54km] CS-CS
Mesh Subs to PMP hub	Adjacent Area, same frequency	12km (note 2)
PMP hub to PMP hub	Same area, adjacent frequency	1 guard channel (note 3 and 5)
Mesh Subs to PMP sub	Same area, adjacent frequency	1 guard channel (note 4)

The guidelines are not meant to replace the co-ordination process described in section 7. However, in many (probably most) cases, by following these guidelines, satisfactory psfd levels will be achieved at system boundaries. The information is therefore valuable as a first step in planning the deployment of systems.

Note 1: The dominant interference path is that which requires the highest guideline geographical or frequency spacing

Note 2: The 12km value is based on a hub at a typical 50m height. For other values, the results change to some extent but are always well below the 54 km value calculated for the PMP – PMP case.

Note 3: The single guard channel spacing is based on both interfering and victim systems using the same channel size. The required spacing for other scenarios has not been analysed. The authors believe that in such cases the guard channel should be that of the wider system.

Note 4: The single guard channel spacing for mesh to PMP is based on both interfering and victim systems using the same channel size and may be reduced in some circumstances. The required spacing for other scenarios (differing channel sizes) has not been analysed. The authors believe that in such cases the guard channel should be that of the wider system.

Note 5: In a case of harmonised FDD band plans and/or frequency reassignable TDD systems, the hub to hub case ceases to be dominant.

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5 System Overview

Broadband Wireless Access (BWA) is a term referring to a range of 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, broadband transmission refers to transmission rate of greater than around 1.5 Mbps, though many BWA networks support significantly higher data rates. The networks operate transparently, so users are not aware that services are delivered by radio. There is usually no direct user-to-user traffic. Such connections, if required, are made via a core network.

A typical BWA network supports connection to many user premises within a radio coverage area. It provides a pool of bandwidth, shared automatically amongst the users. Demand from different users is often statistically of low correlation, allowing the BWA network to deliver significant bandwidth-on-demand to many users, with a high level of spectrum efficiency. Significant frequency re-use is employed.

The range of applications is very wide and evolving quickly. It includes voice, data and entertainment services of many kinds. Each subscriber may require a different mix of services, which 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 "last mile" connection to services. Use of radio or wireless techniques result in a number of benefits, including rapid deployment and relatively low "up-front" costs.

5.1 System Architecture

BWA systems often employ multipoint architectures. The term multipoint includes Point-to-Multipoint (PMP) and Multipoint-to-Multipoint (MP-MP). The 802.16.1 project will define a PMP system with hub stations and end user stations communicating over a fully specified air interface. A similar PMP standard has been generated in Europe, in ETSI Project BRAN, which has produced an interoperability standard titled "Hiperaccess". Coexistence specifications for MWS (which includes the requirements for Hiperaccess) have been prepared by the ETSI TM4 committee. In addition, there are a number of proprietary BWA systems, for which the air interface is not standardized.

5.1.1 PMP Systems

PMP systems comprise Base Transceiver Stations (otherwise known as hubs), terminal stations and, in some cases, repeaters. Hubs use relatively wide beam antennas, divided into one or several sectors to provide 360-degree coverage. To achieve complete coverage of an area, more than one hub station may be required. The connection between hubs is not part of the BWA network itself, being achieved by use of radio links, fiber optic cable or equivalent means.

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

5.1.2 MP-MP Systems

Multipoint-to-multipoint (MP-MP) systems have the same functionality as PMP systems. Hub stations are replaced by central stations (access points), which provide connections to core networks on one side and radio connection to other stations on the other. A subscriber station may be a radio terminal or (more typically) a repeater with local traffic access. Traffic may pass via one or more repeaters to reach a subscriber. Antennas are generally narrow beam directional types. By providing means for remote alignment of antennas and suitable network configuration tools, it is possible to achieve high levels of coverage and spectrum efficiency.

5.2 System Components

Broadband Wireless Access systems typically include Base Transceiver Stations (BTS) or hubs, Subscriber Transceiver Stations (STS), subscriber terminals equipment, core network equipment, inter-cell links, repeaters and possibly other equipment. A reference BWA system diagram is provided in Figure 1– Reference Diagram. 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– Reference Diagram. A BWA system contains at least one BTS/Central Station (CS) and a number of STS units. In the figure, the wireless links are shown as zigzag lines connecting system elements.

Inter-cell links may use wireless, fiber, or copper facilities to interconnect two or more BTS/CS units. Inband Inter-cell Links (ILs) may be implemented point to point (PTP) radios that provide a wireless backhaul capability between base stations at rates ranging from DS-3 to OC-3. The advantage of ILs is that they may share a common infrastructure as the PMP systems, e.g. the switch, to minimize overall network rollout costs. Additionally, IL radios can operate under the auspices of the PMP license, thus avoiding the burden of additional licensing and cost associated with out of band PTP systems.

Antennas with a variety of radiation patterns may be employed. In general, a subscriber station utilizes a highly directional antenna.
Some systems deploy repeaters. In a PMP system, repeaters are generally used to improve coverage to locations where the hub(s) have no line of sight within their normal coverage area(s), or alternatively to extend coverage of a particular hub beyond its normal transmission range. A repeater relays information from a hub to one or a group of subscribers. It may also provide a

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connection for a local subscriber. A repeater may operate on the same frequencies downstream as those frequencies that it uses, facing the hub or it may use different frequencies (i.e. demodulate and re-modulate the traffic on different channels). In MP-MP systems, most stations are repeaters, which also provide connections for local subscribers.

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

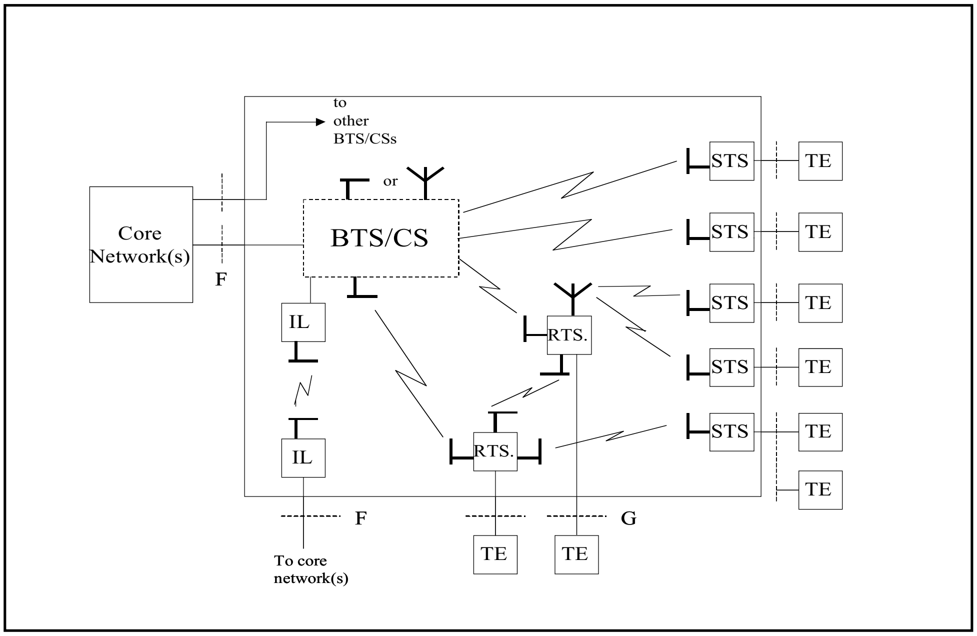

Figure 1– Reference Diagram

Key to Figure 1– Reference Diagram:
BTS/CS : The hub of a PMP system, or Central Station (access point) of a MP-MP system A BTS/CS may, optionally, be divided into two parts; – a control/ interface part and radio part. One control part could support one or a number of radio parts. The interface between the parts is not standardized.
STS: Subscriber Transceiver Station (STS)
TE: The Terminal Equipment. A STS could be connected to more than one TE, dependent on the services required at the user's premises. The TE/STS interface could be standardized (e.g. telephone interface) or proprietary.
RPT: A Repeater Station, with optional connection to local terminal equipment.
IL: An In-band (Inter-cell) Link. Note that an in-band link could be used to connect a remote hub to a convenient access point of a core network or, alternatively, could provide a connection between two hubs.

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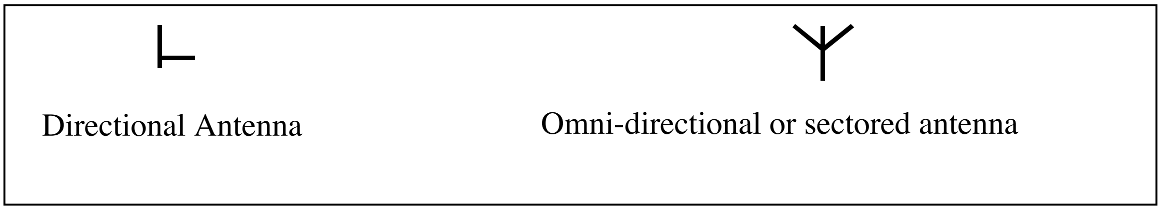

Figure 2– Antenna Symbols

5.3 Medium Overview

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

5.3.1 Interference Scenarios

5.3.1.1 Forms of Interference

Interference can be classified into two broad categories: co-channel interference and out-of-channel interference. These manifest themselves as shown in Figure 3- Forms of Interference.

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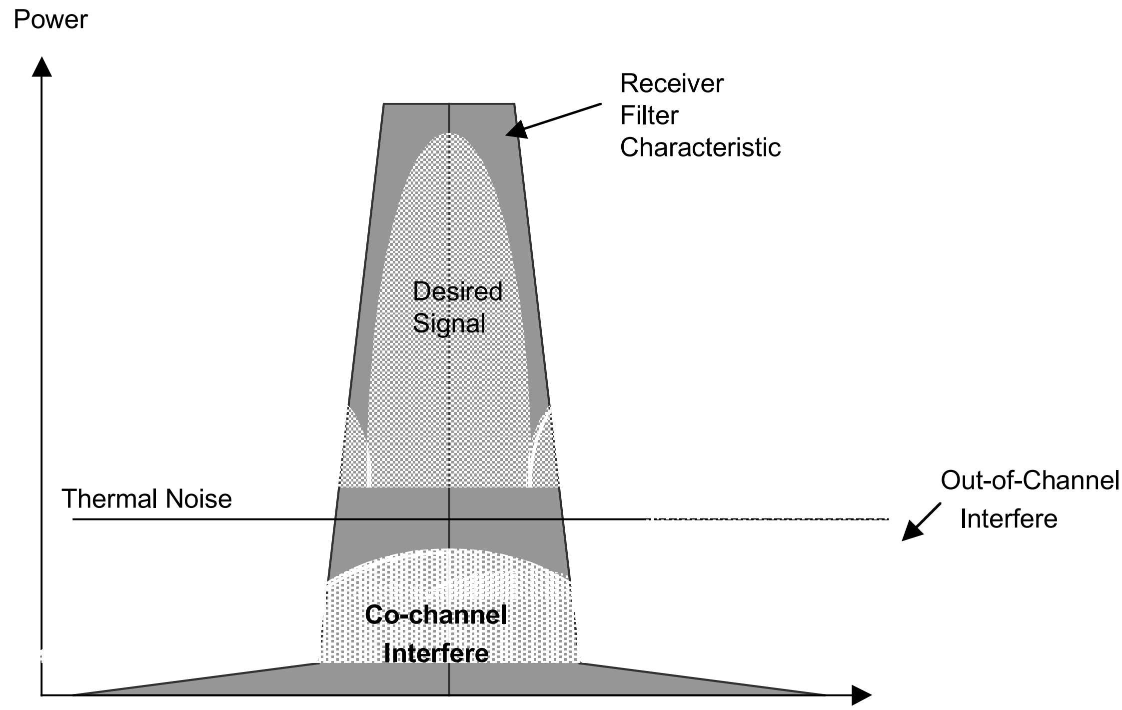

Figure 3- Forms of Interference

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

An out-of-channel interfere is also shown. Here, there are two sets of parameters which determine the total level of interference:

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

additional attenuation factor equal to the relative rejection of the filter's stopband at the frequency of the interfering signal.

It cannot be determined which of the two forms of interference from an out-of-channel interfere will dominate without quantitative input on equipment parameters.

5.3.1.2 Acceptable Level of Interference

A fundamental property of any millimetric-wave BWA system is its link budget, in which the range of the system is computed for a given availability, given rain fading. During the designed worst-case rain fade, the level of the desired received signal will fall until it just equals the noise floor plus the signal-to-noise ratio of the receiver. A simple way to introduce a margin for interference into the link budget is to increase the noise floor by a factor which accounts for the additive interference that will be considered as additional noise. For example, consider a receiver with 6 dB noise figure. The thermal noise floor is –168 dBm/Hz. Interference of –168 dBm/Hz would double the total noise, or degrade the link budget by 3 dB. Interference of –174 dBm/Hz, 6 dB below the thermal noise floor, would increase the total noise by 1 dB to –167 dBm/Hz, or degrade the link budget by 1 dB. A criterion of 1 dB link budget degradation has been used for BWA interference analysis in section 5.2.1.

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

5.3.1.3 Interference Paths

5.3.1.3.1 Victim Hub

Figure 4 - Interference Sources to a BWA Hub shows main sources of interference where the victim receiver is a BWA hub, having a sectoral-coverage antenna.

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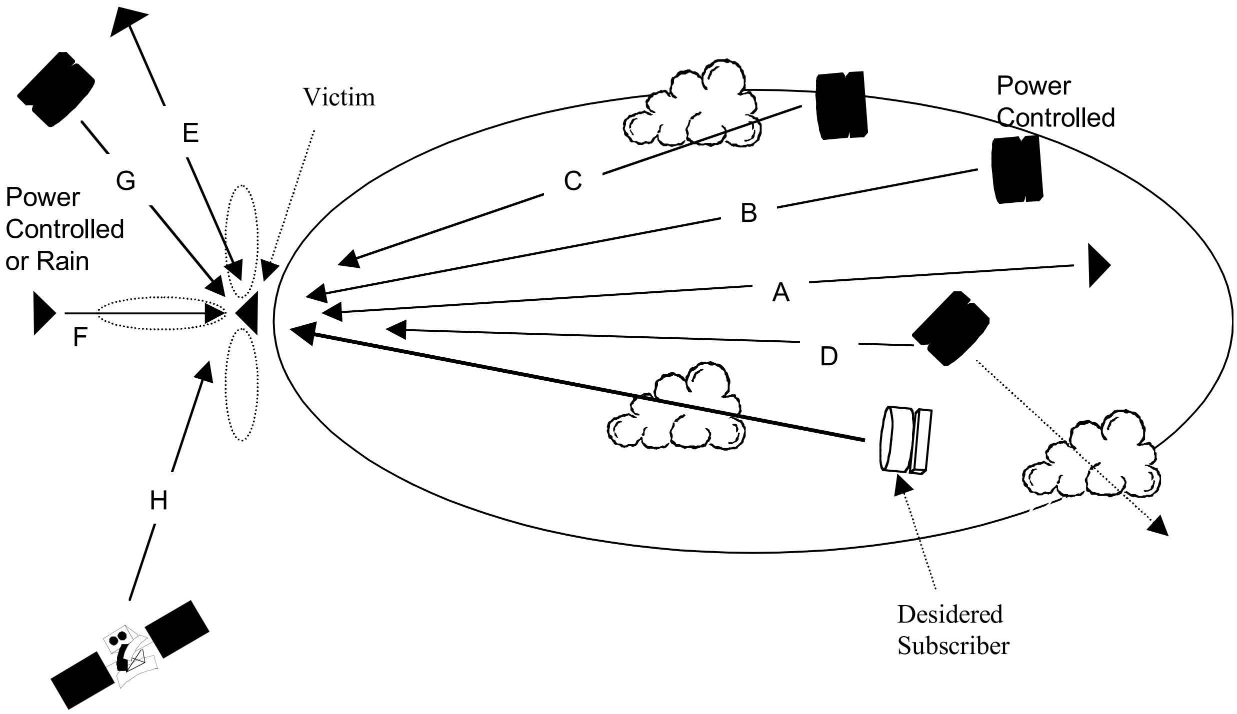

Figure 4 - Interference Sources to a BWA Hub

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

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

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

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

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

Case E is another case of hub-to-hub interference. In this case, the interfering hub's main beam is in the victim's sidelobe or backlobe. There is a reflexive case (not shown) of the interfering hub's sidelobe in the victim's main lobe. As BWA systems tend to use intensive frequency reuse, it is likely that Case A concerns will dominate rather than Case E.

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

Case G covers interference from a subscriber antenna to the victim hub's sidelobe or backlobe. Referring to the commentary concerning Cases B and C, we need only consider the clear air case, but assume the interfere has turned down its power. As hub 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 practice. As long as hub antennas are never up-tilted, this interference should always fall into a (vertical) sidelobe of the victim.

With the above simplifying assumptions, the dominant sources of interference which require detailed modeling are shown below.

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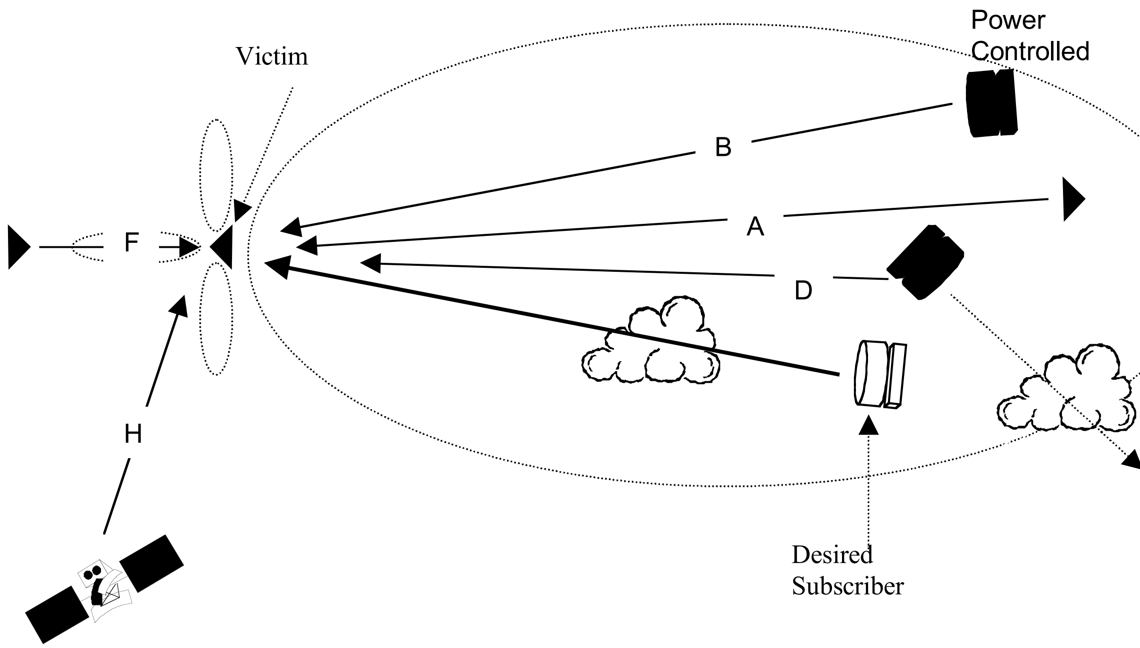

Figure 5 - Simplified Model for Interference to a BWA Hub

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

5.3.1.3.2 Victim Subscriber Station

Figure 6 - Interference Sources to a BWA Subscriber Station shows the main sources of interference to a subscriber station having a narrow beamwidth antenna.

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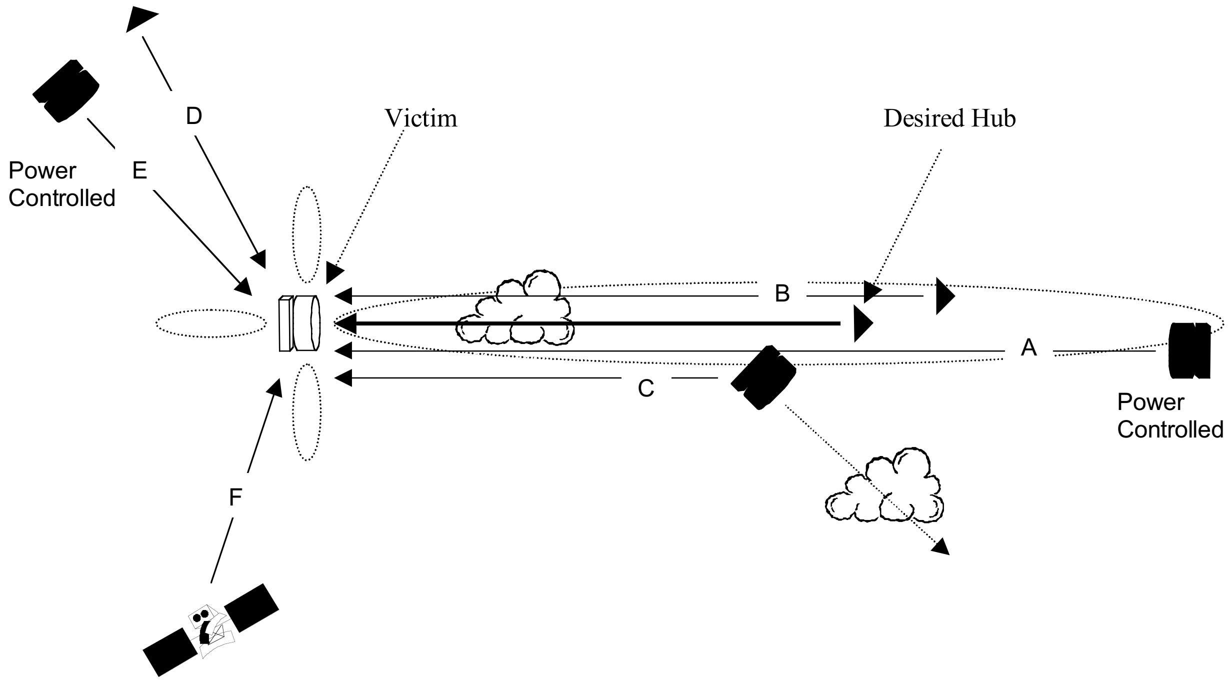

Figure 6 - Interference Sources to a BWA Subscriber Station

The victim subscriber station is shown along with its (ellipses) radiation pattern. The hub supplying the desired signal is shown on center left and interferers in remaining locations. The victim subscriber cases are fundamentally different from the victim hub 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.

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

Case B covers hub-to-subscriber interference.

Case C covers the case of a narrow-beam transmitter (BWA or point-to-point) or satellite uplink which is at full power, due to rain in its path, but radiates 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 interfere.

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

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

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

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6 Equipment Design Parameters

This section provides recommendations for equipment design parameters which significantly affect interference levels and hence co-existence. Recommendations are made for the following BWA equipment: base station equipment, subscriber equipment, repeaters and inter-cell links (including PTP equipment).

Recommendations are for both transmitter and receiver portions of the equipment design. The recommended limits are applicable over the full range of environmental conditions for which the equipment is designed to operate including temperature, humidity, input voltage, etc.

Note the following design parameters apply to Frequency Range 2 (23.5-43.5 GHz), unless otherwise indicated.

6.1 Transmitter Design Parameters

This section provides recommendations for the design of both subscriber and base station transmitters, which are to be deployed in Broadband Wireless Access systems. Recommendations are also made for repeaters and inter-cell links.

6.1.1 Maximum EIRP Spectral Density Limits

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

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

In preparing this Practice, emission limits from current (July 2000) US FCC, Industry Canada and ITU-R regulations or recommendations were reviewed. Table 2 - Comparison of typical Regulatory and Coexistence Practice Simulation EIRP spectral density values depicts some example regulatory EIRP spectral density limits.

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Table 2 - Comparison of typical Regulatory and Coexistence Practice Simulation EIRP spectral density values

Terminal	Example Regulatory Limits (dBW/MHz)	Simulation Assumptions (dBW/MHz)
BTS	+14	-1.47
STS	+30	13.53
PtP	+30	+25.01
Repeater facing BTS	+30	Not Performed
Repeater facing STS	+14	Not Performed
Mesh	+30	0

Although it is possible that the regulatory limits may be approached in the future, these emission limits are significantly higher (e.g., 15 dB) than supported by most currently available equipment. They are also significantly higher than utilized by the coexistence simulations which were the basis for the recommendations contained in this Practice and which are also shown in Table 2 - Comparison of typical Regulatory and Coexistence Practice Simulation EIRP spectral density values. The parameters used for BTS and STS in coexistence simulations are as follows:

Tx Power: +24 dBm (-6 dBW)
STS Antenna Gain: +34 dBi
BTS Antenna Gain: +19 dBi
"Carrier Bandwidth": 28 MHz (+14.47 dB-MHz)

It is recommended that any regulatory limits be viewed by the reader as future potential capabilities and that where possible, actual deployments should use much lower EIRP spectral density values as suggested in Sections 6.1.1.1 through 6.1.1.5. If systems are deployed using the maximum regulatory limits, they should receive a detailed interference assessment, unless they are deployed in isolated locations, remote from adjacent operators. The assessment is needed to check consistency with the one guard channel recommendation for the same area/adjacent channel case (see Recommendation 8 in Section 4.1).

6.1.1.1 Base Transceiver Station (BTS)

A BTS conforming to the recommendations of this practice should not produce an EIRP power spectral density exceeding +14 dBW/MHz. However, it is strongly recommended that a maximum EIRP power spectral density of 0 dBW/MHz be used in order to comply with the one guard channel recommendation for the same area/adjacent channel case (see Recommendation 8 in Section 4.1). The spectral density should be assessed with an integration bandwidth of 1 MHz;

i.e. these limits apply over any 1 MHz bandwidth. Note: For the specific sub-band 25.25-25.75 GHz, the recommended BTS EIRP spectral limits as stated in ITU-R Document 7D-9D/68-E should be observed, and are stated as follows:

The e.i.r.p. spectral density for each transmitter of a BTS in a BWA system should not exceed the following values in any 1 MHz band for the elevation angle θ above the local horizontal plane:

+14	*dBW*	*for* $0° \le \theta \le 5°$	*(1)*
+14 - 10 log (θ/5)	*dBW*	*for* $5° < \theta \le 90°$	*(2)*

where

θ is the elevation angle above the local horizontal plane.

In the direction toward any geostationary (GSO) Data Relay Satellite (DRS) orbit location specified in ITU-R Recommendation SA.1276[1], the e.i.r.p. spectral density limits[2] of a BTS shall not exceed +8dBW/MHz if the elevation angle above the local horizontal plane[3] is between 0° and 20°.

6.1.1.2 Subscriber Transceiver Station (STS)

A STS conforming to the recommendations of this practice should not produce an EIRP spectral density exceeding +30 dBW/MHz. However, it is strongly recommended that a maximum EIRP power spectral density of +15 dBW/MHz be used in order to comply with the one guard channel recommendation for the same area/adjacent channel case (see Recommendation 8 in Section 4.1). Note the stated limits apply to the STS operating under faded conditions (rain attenuation). A lower limit is specified for unfaded conditions, as described in Section 6.1.2.

Note: For the specific sub-band 25.25-25.75 GHz, the recommended subscriber EIRP limits as stated in ITU-R Document 7D-9D/68-E should be observed, and are stated as follows:
Transmitter of a STS in a BWA system or transmitters of point-to-point fixed stations:
Where practicable, the e.i.r.p. spectral density for each transmitter of a STS of a BWA system, or transmitters of point-to-point fixed stations in the direction of any geostationary (GSO) Data Relay Satellite (DRS) orbit location specified in ITU-R Recommendation ITU-R SA.1276 should not exceed +24 dBW in any 1 MHz.

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[1] The ITU-R Recommendation ITU-R SA.1276 identifies the following geostationary DRS orbital positions: 16.4E°, 21.5°, 47°E, 59°E, 85°E 90°E, 95°E, 113°E, 121°E, 160°E, 177.5°E, 16°W, 32°W, 41°W, 44°W, 46°W, 49°W, 62°W, 139°W, 160°W, 170°W, 171°W, and 174°W.

[2] The e.i.r.p. spectral density radiated towards a geostationary DRS location should be calculated as the product of the transmitted power spectral density and the gain of the omnidirectional or sectoral antenna in the direction of the DRS. In the absence of a radiation pattern for the BTS antenna, the reference radiation pattern of Recommendation ITU-R F.1336 should be used. The calculation should take into account the effects of atmospheric refraction and the local horizon. A method for calculating the separation angles is given in Annex 2 to Recommendation ITU-R F.[PMP].

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6.1.1.3 Repeater Station Facing Base Transceiver Station

There are several possible types of repeaters (see section on System Overview). From the point of view of EIRP spectral density limits, two recommendations are given, according to the direction faced by the repeater and type of antenna used. The first recommended limit applies to situations where a repeater uses a sectored or omni directional antenna, typically facing a number of subscribers. The second case applies where a repeater uses a highly directional antenna, typically facing a hub or single subscriber.
BWA repeater stations systems deploying directional antennas and conforming to the equipment requirements of this practice should not produce an EIRP spectral density exceeding +30 dBW/ MHz. However, it is strongly recommended that a maximum EIRP power spectral density of +15 dBW/MHz be used in order to comply with the one guard channel recommendation for the same area/adjacent channel case (see Recommendation 8 in Section 4.1).

6.1.1.4 Repeater Station Facing Subscriber Transceiver Station

BWA repeater stations deploying omni-directional or sectored antennas and conforming to the equipment requirements of this practice should not produce an EIRP spectral density exceeding +14dBW/ MHz. However, it is strongly recommended that a maximum EIRP power spectral density of 0 dBW/MHz be used in order to comply with the one guard channel recommendation for the same area/adjacent channel case (see Recommendation 8 in Section 4.1).

6.1.1.5 Inband Inter-cell Link Station (IILS)

IILS radios typically employ high gain antennas to facilitate ranges that are at least twice the radius of a typical BTS, e.g. 8-10 km. Based on this, the following typical parameters are assumed for a 28 GHz IILS transmitter:

G_{TX} = 42 dBi
P_{TX} = 0 dBW/carrier
Carrier BW = 50 MHz
Modulation = 16 QAM (data rate~150 Mb/s)

$$PSD = P_{TX} - 10 \log (BW) = -17 \text{ dBW/MHz} \quad (3)$$
$$EIRPSD = P_{TX} - 10 \log (BW) + G_{TX} = +25 \text{ dBW/MHz} \quad (4)$$

where
PSD is the power spectral density (dBW/MHz);
P_{TX} is the transmitter power (dBW/Carrier);
BW is the bandwidth of the carrier (MHz);

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EIRPSD is the EIRP Spectral density (dBW/MHz);
Allowing for some extra margin, the EIRPSD may be as high as 30 dBW/MHz.

Therefore, IILS radios conforming to the equipment recommendations of this Practice should not produce an EIRP spectral density exceeding +30 dBW/MHz. However, it is strongly recommended that a maximum EIRP power spectral density of +15 dBW/MHz be used in order to comply with the one guard channel recommendation for the same area/adjacent channel case (see Recommendation 8 in Section 4.1).

6.1.2 Power Control

6.1.2.1 Upstream Power Control

A STS conforming to the equipment design parameters recommended by this practice should employ upstream power control of at least 15 dB of range.

6.1.2.2 Down Stream Power Control

This practice assumes that no downstream power control is employed. However, it is recommended that the minimum power necessary to maintain the link be employed. And in all cases, the recommended limits given in Section 6.1.1 should be met.

6.1.3 Frequency Tolerance or Stability

The system should operate within a frequency stability of +/- 10 parts per million. [NOTE: This specification is only for the purposes of complying with *coexistence* requirements. The stability requirements contained in the PHY specifications may be more stringent, particularly for the base transceiver station. In addition, it is highly recommended that the STS transmit frequency be controlled by using a signal from the downstream signal(s).]

6.1.4 Out of Band Unwanted Emissions

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

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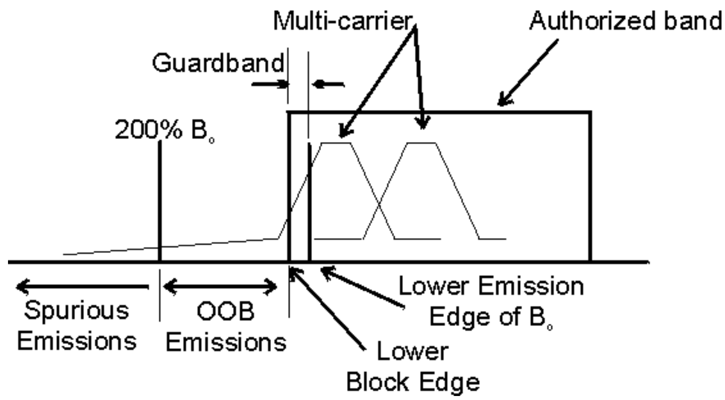

Figure 7 – Unwanted Emissions

As indicated in Figure 7 – Unwanted Emissions, single carrier or multi-carrier transmissions, whose occupied bandwidth is totally within the authorized band, will emit some power into adjacent bands. These unwanted emissions include out-of-band (OOB) emissions (within 200% of the emission occupied bandwidth (B_o) of the authorized band edge) and spurious emissions (beyond this 200% point).

6.1.4.1 Unwanted Emission Limit

Unwanted emissions spectral density should be attenuated by at least A (dB) below the total mean output power P_{mean} as follows:

(1) For a single carrier transmitter (see section A.1.2) :

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

(2) For a multi-carrier transmitter or multi-transmitters (excluding OFDM) into a common final stage amplifier (see Annex A -section A.1.3):

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

Note: Several transmitters into a common non-active antenna cannot use the multi-carrier mask for the composite signal. In this case the appropriate mask applies to the individual transmitter.

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

Emissions shall not exceed an absolute level of -70 dBW/MHz.

Note: Unwanted Emission in Europe

Within Europe the CEPT/ETSI limits of Draft EN 301 390 should be applied which has limits that are 10 dB more stringent than CEPT/ERC Recommendation 74-01 for noise-like emissions over certain frequency bands.

Note: Within the +/-250% of the channel a specific spectrum mask applies which should be taken from the appropriate standard documented by ETSI.

The following is extracted from Draft EN301-390 V1.1.1 (1999-07):

"Spurious Emissions and Receiver immunity at Equipment / Antenna Port of Digital Fixed Radio Systems"

4.1.3 Point-to-Multipoint equipment with fundamental emission above 21.2 GHz

The CEPT/ERC Recommendation 74-01 [4] shall apply for spurious emissions in the frequency range 9 kHz to 21.2 GHz and above 43.5 GHz.

For spurious emissions falling in the range 21.2 GHz to 43.5 GHz the tighter limits shown in Figure 8- Systems for Channel separation 1<CS≤10 MHz *and* Figure 9 - Equipment for Channel separation CS>10 MHz *shall apply:*

In the same Figures, for comparison, the less stringent limits from CEPT/ERC Recommendation 74-01 [4] are also shown.

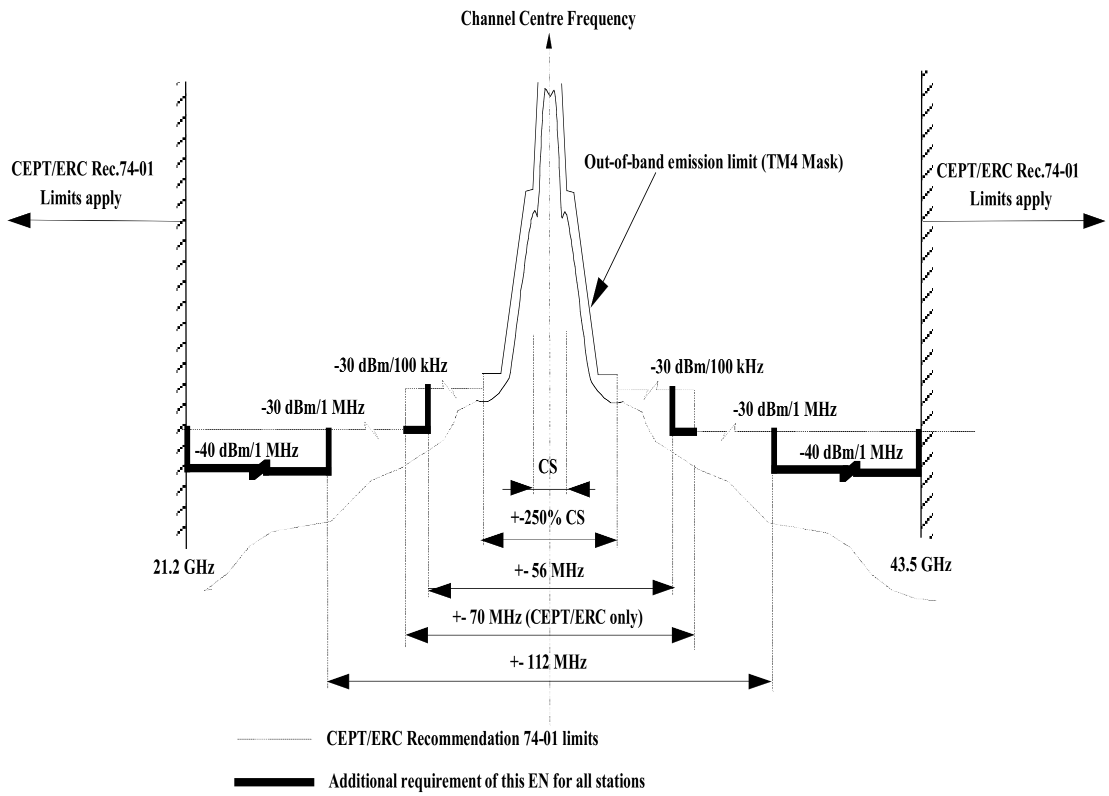

Figure 8- Systems for Channel separation 1<CS≤10 MHz

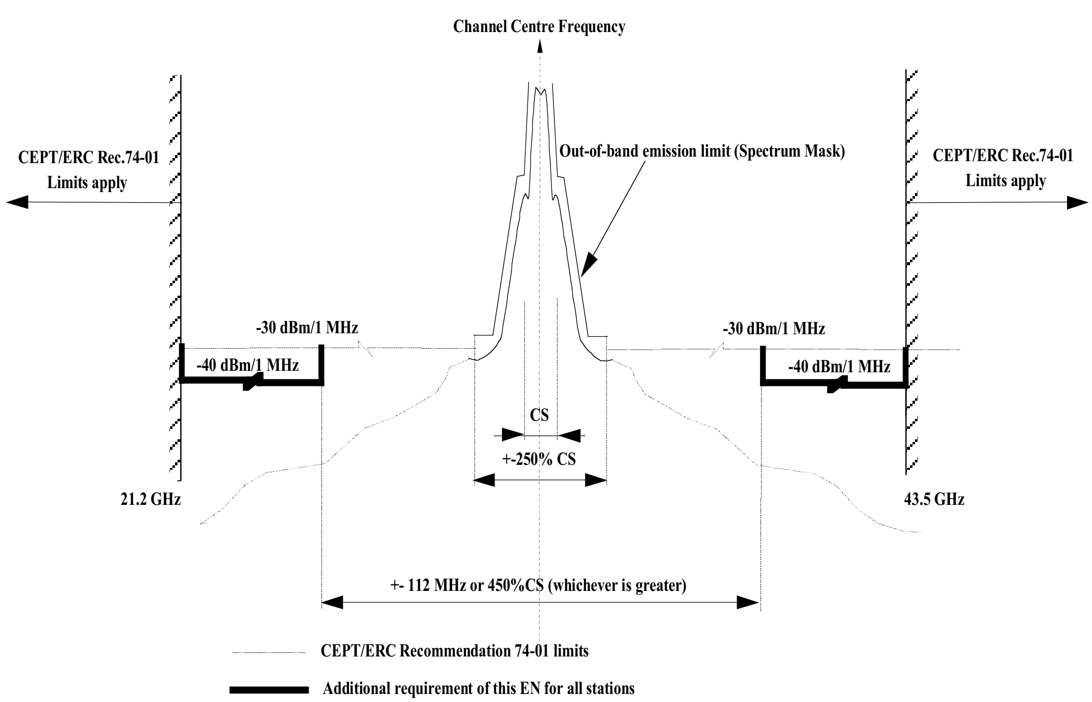

Figure 9 - Equipment for Channel separation CS>10 MHz

6.2 Antenna Parameters

The following antenna parameters apply to Frequency Range 2 (23.5-43.5 GHz), unless otherwise indicated.
In considering coexistence, the operator needs to consider antenna radiation pattern in the azimuth (AZ) and elevation (EL) planes relative to the required coverage footprint. For purposes of consistency and ease of implementation, the ability to select either horizontal or vertical polarization without the need for concern for differences in the RPE's is considered very important. Hence, the AZ and EL RPE's are independent of polarization. The polarization discrimination is specified in the tabular and graphical form below.

6.2.1 Polarization

Two linear polarization orientations, horizontal and vertical, are recommended. The required polarization purity is captured in the specification of antenna cross-polar discrimination (XPD) in the next section. Also, the Radiation Pattern Envelopes (RPEs) of this recommendation, described later, are independent of polarization.

6.2.2 Base Transceiver Station Antenna

6.2.2.1 Electrical Classes

The performance of BTS antennas is divided into two electrical classes. Depending on the deployment environment, the specific antenna class may be chosen to provide suitable coverage.

The distinguishing factor between the classes is the severity of interference into other transceivers. Although it is outside the scope of this paper to address intra-system interference, selection of antennas may be principally determined by interference arising from within an operator's own network rather than from external sources.

A) Electrical Class 1

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

B) Electrical Class 2

Electrical Class 2 antennas are meant for operation in environments in which interference levels could be potentially significant and cause problems under certain conditions.

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In such conditions, Class 2 antennas with higher levels of discrimination in side lobes and back lobes need to be deployed to provide acceptable performance of the system and mitigate inter-system interference.

6.2.2.1.1 Azimuth Radiation Pattern Envelopes

This section describes radiation pattern envelopes for the two Electrical Classes of antenna.

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

The following figures illustrate the recommended copolar and crosspolar RPEs for the two Electrical Classes of antenna.

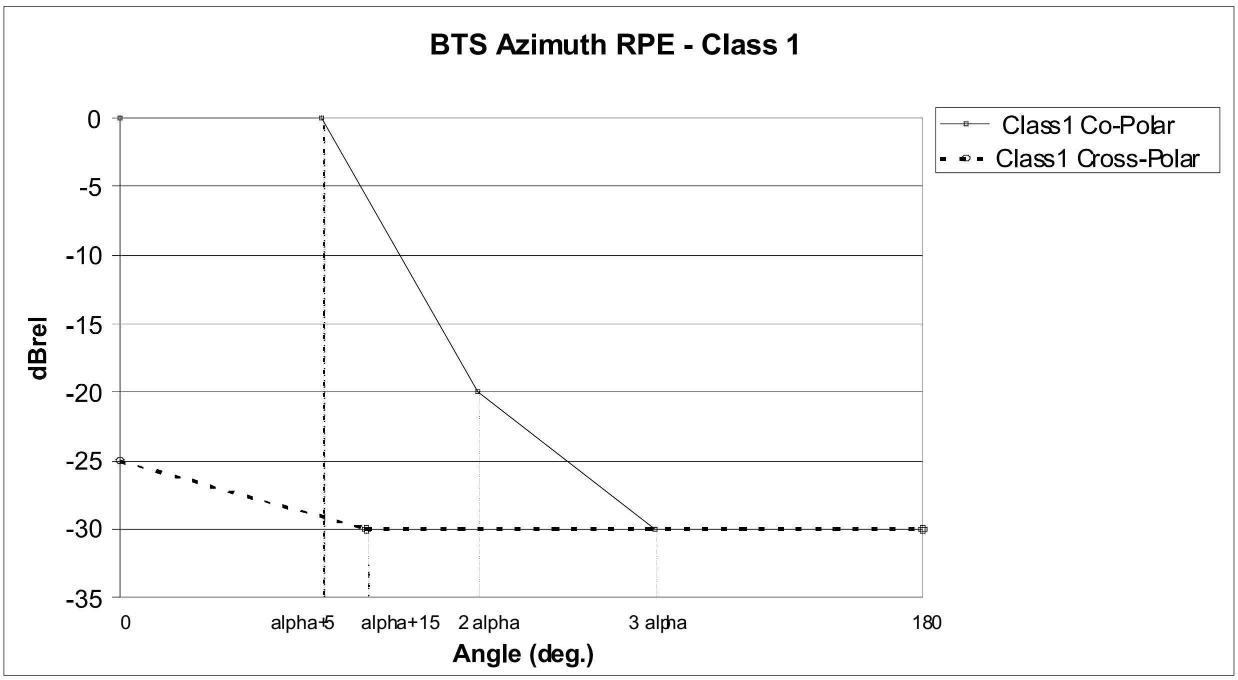

Figure 10 – BTS RPE in the Azimuth plane – Electrical Class 1

Table 3 - BTS RPE in the Azimuth plane – Electrical Class 1

Angle (degrees)	Class1 Co-Polar (dBrel)	Class1 Cross-Polar (dBrel)
0	0	-25
alpha+5	0	-
alpha+15	-	-30
2*alpha	-20	-
3*alpha	-30	-
180	-30	-30

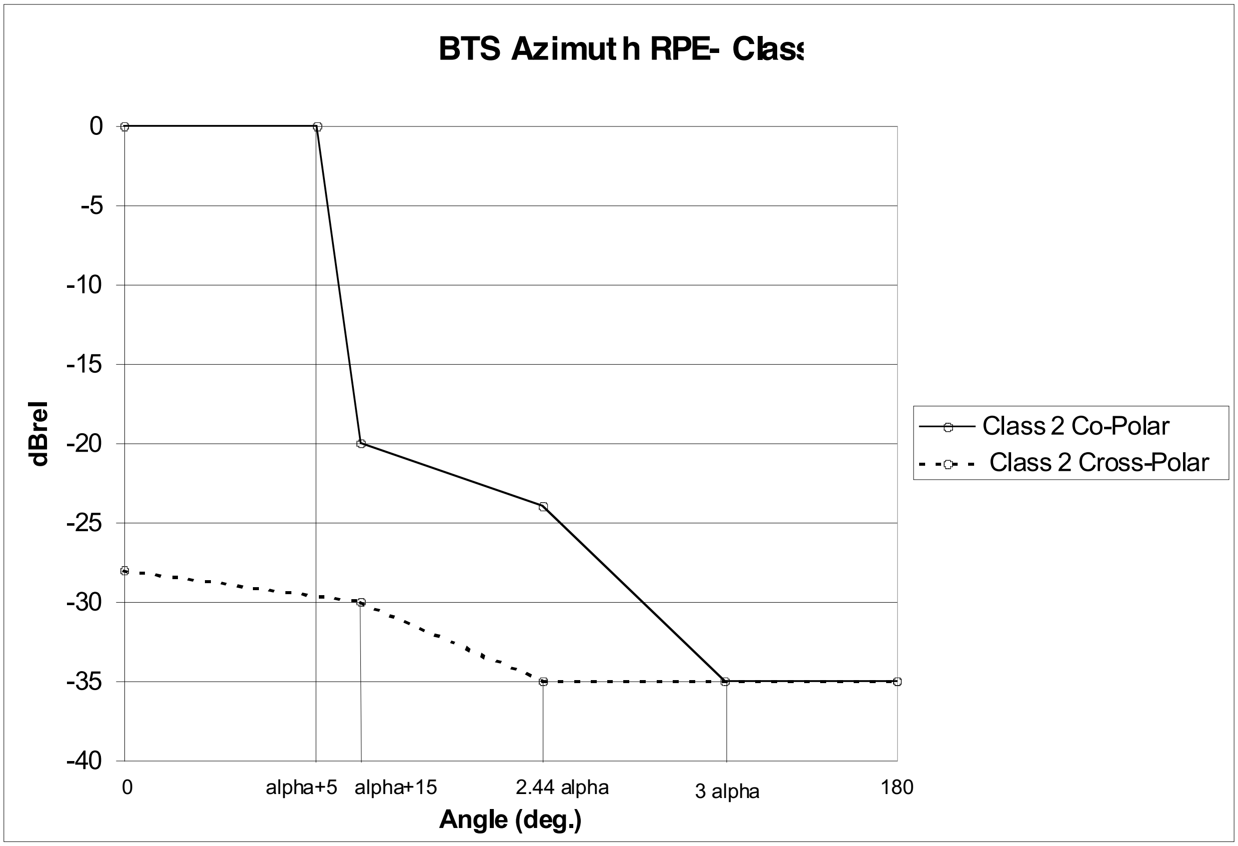

Figure 11- BTS RPE in the Azimuth plane – Electrical Class 2

Table 4 - BTS RPE in the Azimuth plane – Electrical Class 2

Angle (degrees)	Class2 Co-Polar (dBrel)	Class2 Cross-Polar (dBrel)
0	0	-28
alpha+5	0	-
alpha+15	-20	-30
2.44* alpha	-24	-35
3*alpha	-35	-
180	-35	-35

6.2.2.1.2 Elevation Radiation Pattern Envelopes

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The Elevation Radiation Pattern Envelopes (RPEs) should be specified both above and below the local horizon, to provide isolation, improve coexistence, and to ensure efficient use of radiated power. The pattern below the horizon should be specified as a minimum in order to reduce coverage nulls that would require an increase in radiated power by the subscriber antenna.

The elevation RPE below the horizon is specified in terms of β, where 2β is the 3dB beamwidth in the elevation plane.

This specification will follow accepted practices for the specification of elevation radiation pattern envelopes that provide for the 0° angle to be directed at the local horizon, the 90° angle directed overhead, and the -90° angle directed downward.
It may be necessary in practical deployments to use electrical or mechanical tilt, or a combination of both, to achieve the required cell coverage, taking into account the surrounding terrain, for example.

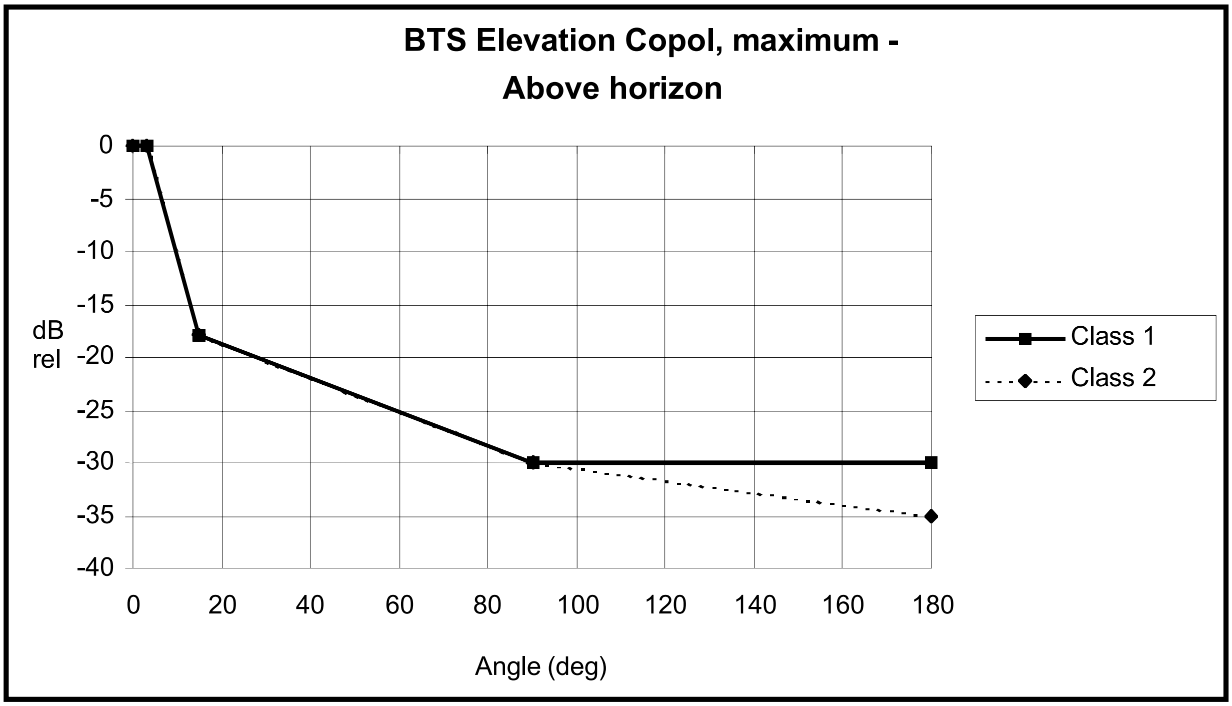

Figure 12 – BTS Elevation Co-polarized maximum above the horizon

Table 5 - BTS Elevation Co-polarized maximum above the horizon

Angle (degrees)	Class1 Co-Polar (dBrel)	Class2 Cross-Polar (dBrel)
0	0	0
beta	0	0
15	-18	-18
90	-30	-30
180	-30	-35

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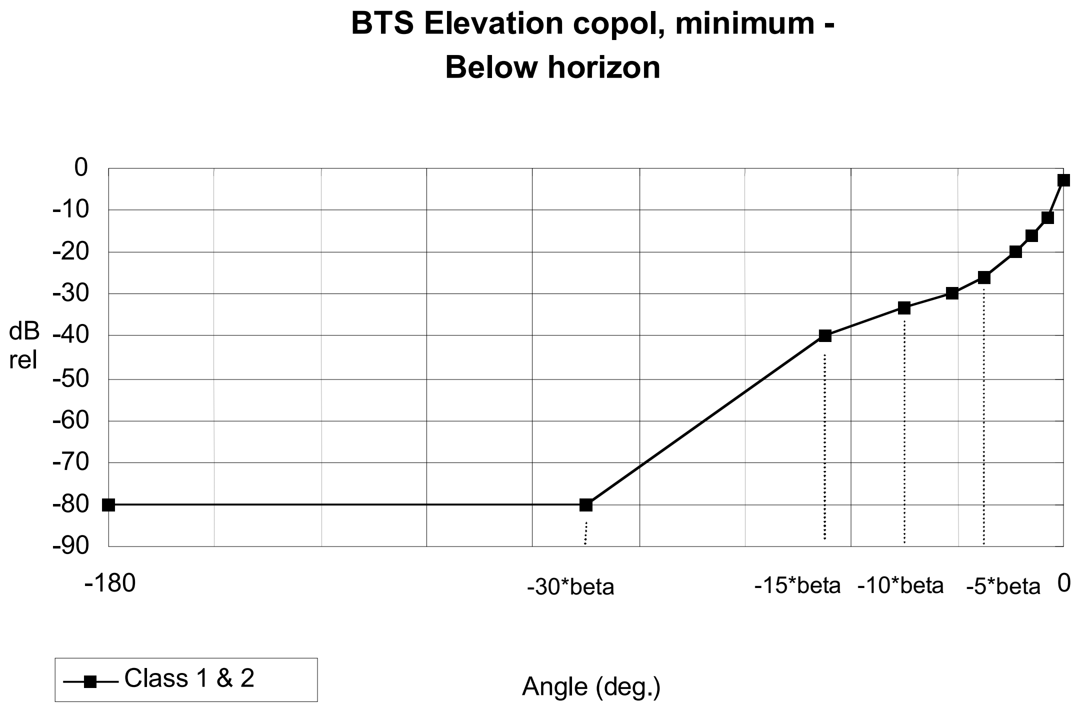

Figure 13- BTS Co-Polarized minimum below the horizon

Table 6 - BTS Co-Polarized minimum below the horizon

Angle (degrees)	Class 1 & 2 Co-Polar Minimum (dBrel)
0	-3
-beta	-12
-(2*beta)	-16
-(3*beta)	-20
-(5*beta)	-26
-(7*beta)	-30
-(10*beta)	-33
-(15*beta)	-40
-(30*beta)	-80
-90	-80
-180	-80

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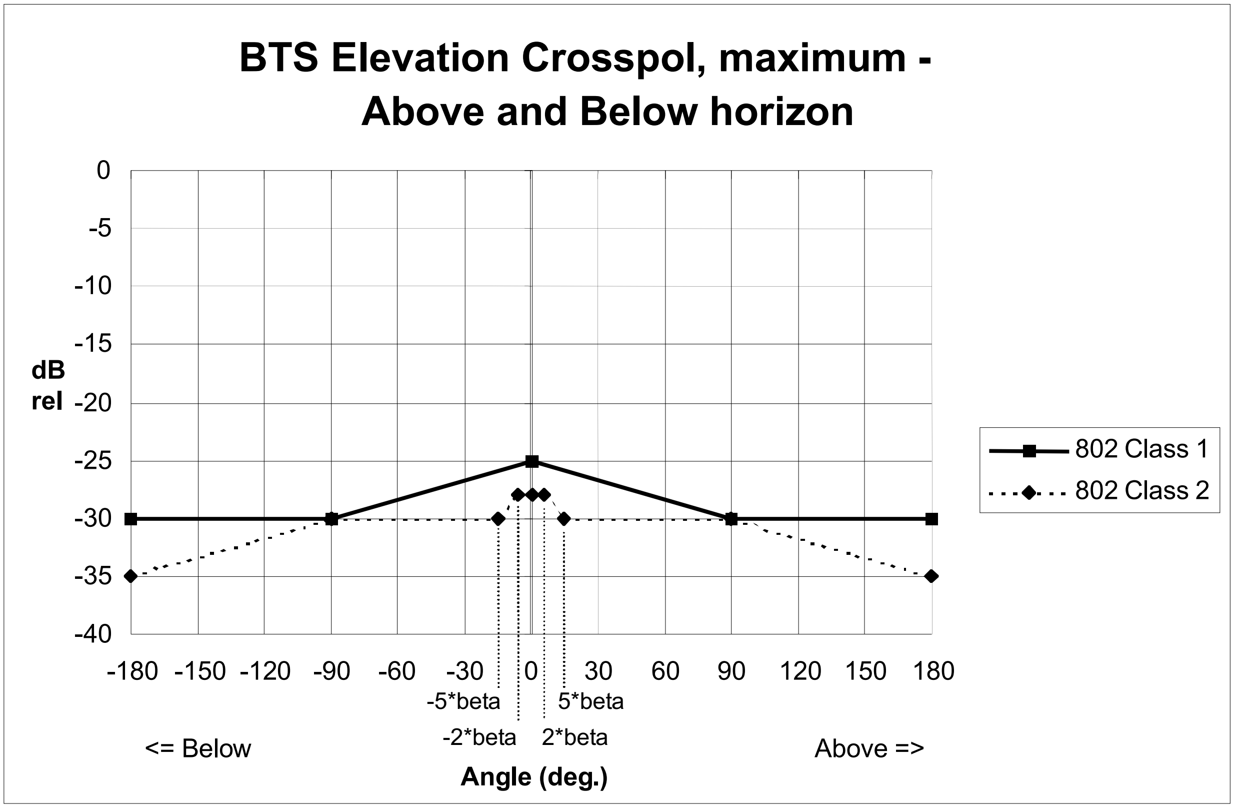

Figure 14– BTS Cross-Polarized maximum above and below the horizon

Table 7 - BTS Cross-Polarized maximum above and below the horizon

Angle (degrees)	Class1 Co-Polar (dBrel)	Class2 Cross-Polar (dBrel)
-180	-30	-35
-90	-30	-
-(5*beta)	-	-30
-(2*beta)	-	-28
0	-25	-28
(2*beta)	-	-28
(5*beta)	-	-30
90	-30	-
180	-30	-35

6.2.3 Subscriber Transceiver Station

BWA systems employ STS antennas that are highly directional, narrow-beam antennas. Although it is not as important for coexistence as the BTS RPE, the RPE of the STS antenna is a factor in determining inter-system interference.

6.2.3.1 Radiation Pattern Envelope

The following figures show the RPEs of co- and cross-polar patterns for classes 1, 2 and 3. The required side lobe level and front-to-back ratio of the STS antenna depends on the coexistence scenario, C/I requirements of the radios, rain region, and the pattern of BTS antenna. It is recommended here that all of the above-mentioned parameters be taken into consideration in choosing the right class of antenna.

In the following graphs, 2α is the 3 dB (or half-power) beamwidth of the antenna. It is also assumed that the same RPE should apply to both E- and H-plane. There is, however, no requirement on the symmetry of the antenna patterns as long as they meet the following RPEs.

< Class 1 figure to be modified>

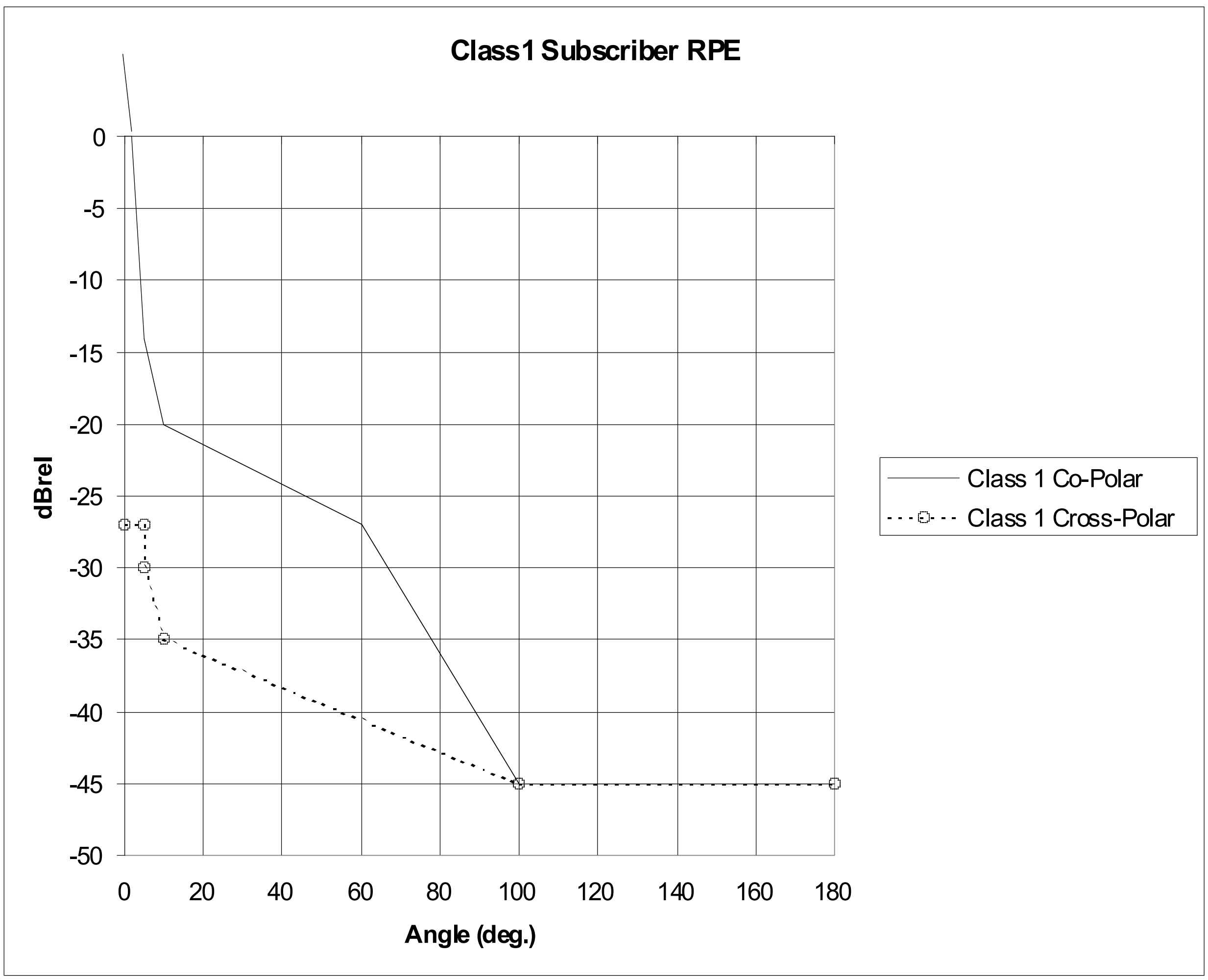

Figure 15 – STS RPE Class 1

Table 8- STS RPE Class 1

Angle (degrees)	Class 1 Co-Polar (dBrel)	Class 1 Cross-Polar (dBrel)
0	0	-27
alpha	0	-
4.99	-	-27
5	-14	-30
10	-20	-35
60	-27	-
100	-45	-45
180	-45	-45

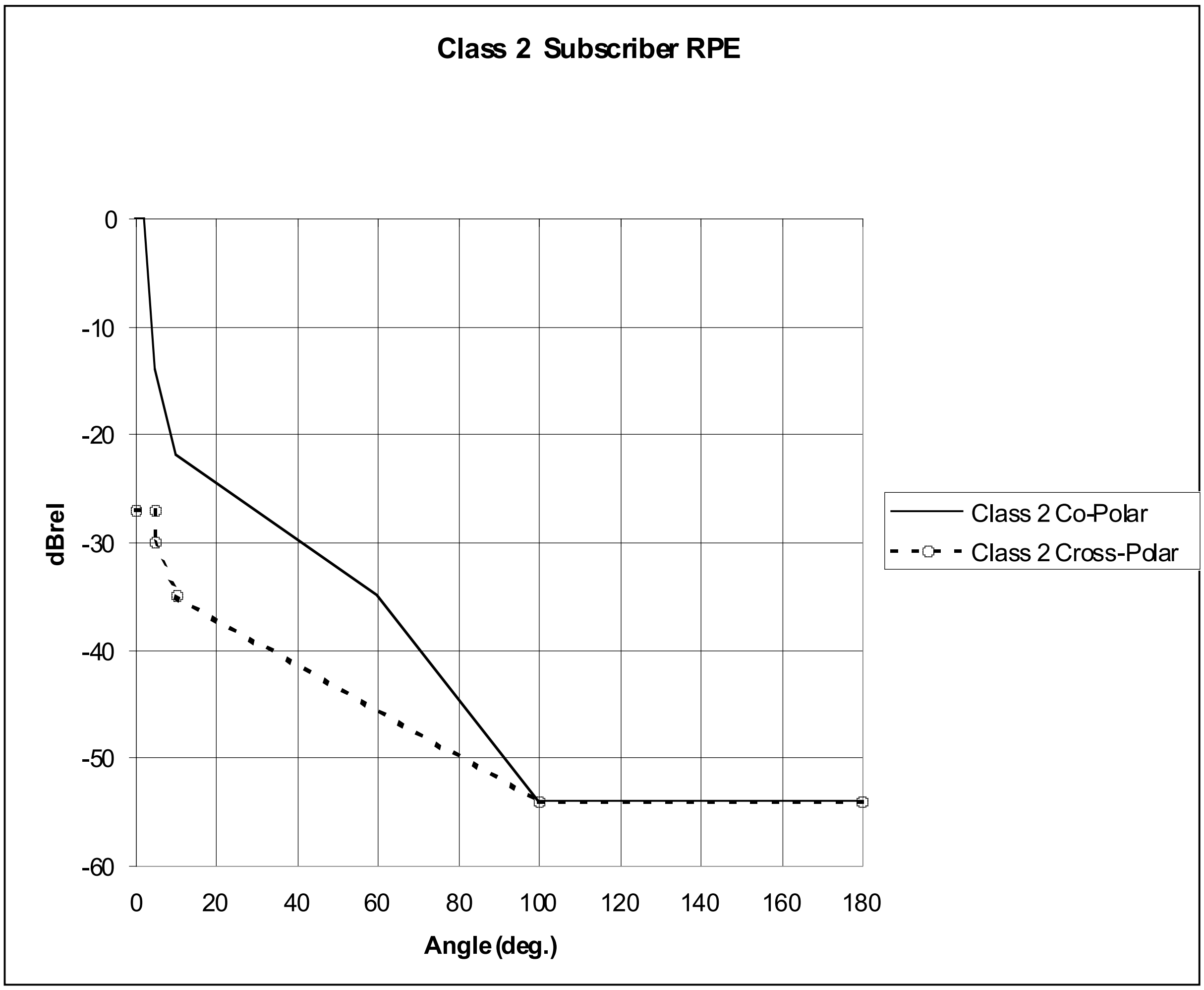

Figure 16 - STS RPE Class 2

Table 9 - STS RPE Class 2

Angle (degrees)	Class 2 Co-Polar (dBrel)	Class 2 Cross-Polar (dBrel)
0	0	-27
alpha	0	-
4.99	-	-27
5	-14	-30
10	-22	-35
60	-35	-
100	-54	-54
180	-54	-54

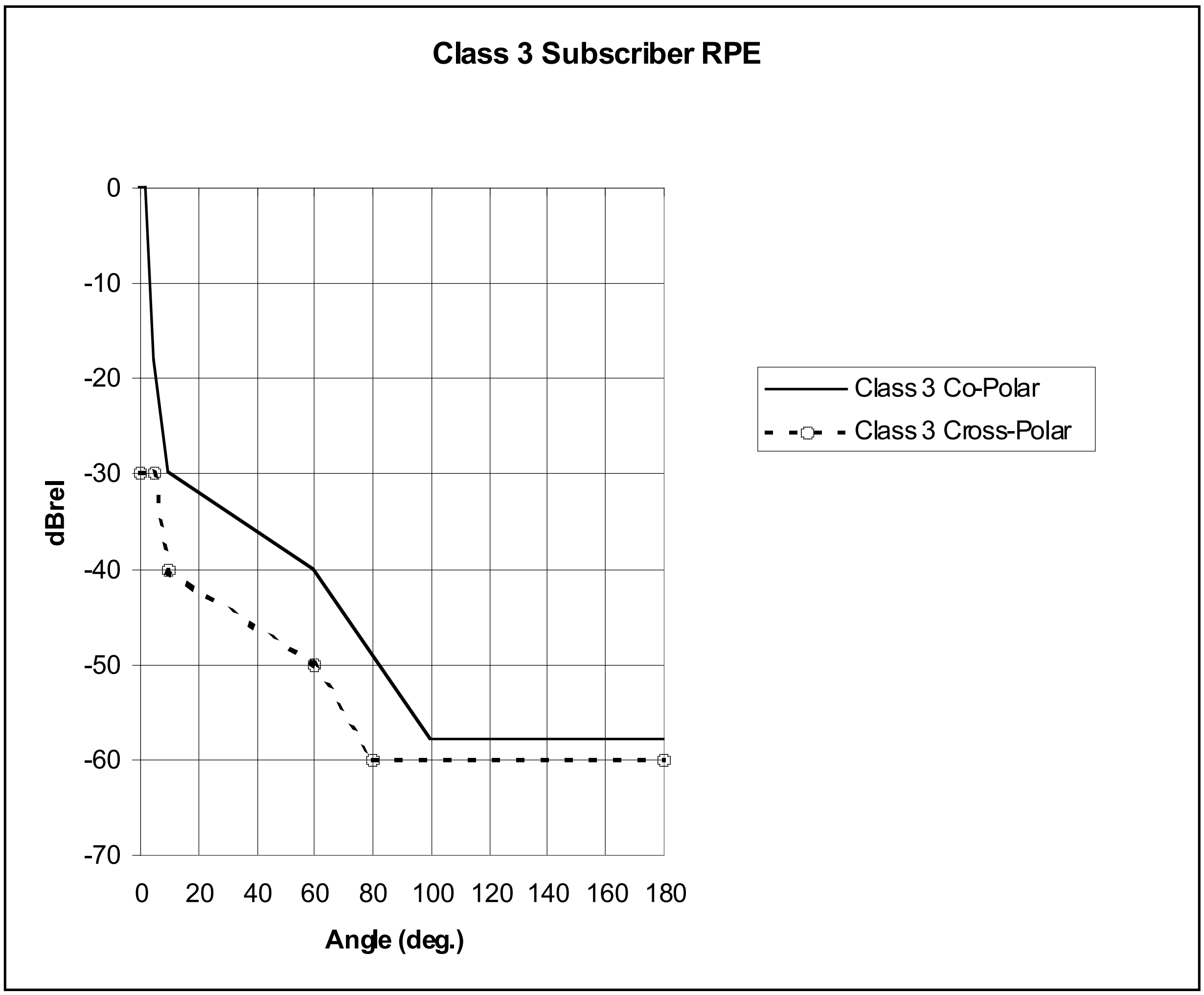

Figure 17 - STS RPE Class 3

Table 10 - STS RPE Class 3

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Angle(degrees)	Class 3 Co-Polar (dBrel)	Class 3 Cross-Polar (dBrel)
0	0	-30
alpha	0	-
5	-18	-30
10	-30	-40
60	-40	-50
80	-	-60
100	-58	-
180	-58	-60

6.2.4 Mechanical Characteristics

This section discusses the recommended minimum requirements regarding antenna mechanical requirements for typical environments. However, for harsher environments e.g. hurricane-prone areas, a more robust antenna systems may be required.

6.2.4.1 Wind and Ice Loading

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

6.2.4.2 Water Tightness

Water tightness is important in eliminating unwanted attenuation that would not necessarily be uniform over the antenna aperture and could change the pattern and non-uniformly reduce the distance over which the BTS would operate. In this regard, the antenna should be designed to ensure water ingress is negligible.

6.2.4.3 Temperature and Humidity

The antennas must not suffer performance degradation when subjected to temperature or humidity extremes, which could potentially cause interference. Therefore, antennas should be

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designed to operate within the recommendation of this document over the full temperature and humidity range for which the system is intended to be deployed.

6.2.4.4 Additional Consideration

6.2.4.5 Radomes and Heaters

If radomes are used, all recommended antenna limits included in this practice should be met i.e. with the radomes installed. This includes radome heaters where they are required.

6.2.4.6 Labeling

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

6.2.4.7 Mechanical Adjustment Assembly

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

6.2.4.8 Vibration

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

6.3 Receiver Design Parameters

This section provides recommendations for the design of both subscriber and base station receivers, which are to be deployed in Broadband Wireless Access systems. The parameters for which recommendations are made are those which affect performance in the presence of interference from other BWA systems.

6.3.1 Co-Channel Interference Tolerance

The following paragraphs recommend minimum design standards to allow for interference.

6.3.1.1 Base Transceiver Station

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

The receiver should be capable of operating at the specified BER in the presence of a co-channel interference signal that is 6 dB below the receiver's noise floor, causing a total noise floor degradation of 1.0 dB. The minimum allowable degradation in the receivers effective noise floor of 1.0 dB was chosen as an acceptable degradation level upon which to operate a BWA system while allowing interference levels to be specified in an acceptable manner.

6.3.1.2 Subscriber Transceiver Station

The subscriber receiver may be subjected to adjacent channel interference and co-channel interference from other BWA systems operating in the close proximity to the reference system. Therefore, the receivers intended for subscriber terminal applications should be designed with the proper selectivity and tolerance to interference. The following paragraphs recommend minimum design standards to allow for interference.

The receiver should be capable of operating at the specified BER in the presence of a co-channel interference signal that is 6 dB below the receiver's noise floor, causing a total noise floor degradation of 1.0 dB. The minimum allowable degradation in the receivers effective noise floor of 1.0 dB was chosen as an acceptable degradation level upon which to operate a BWA system while allowing interference levels to be specified in an acceptable manner.

6.3.2 Adjacent Channel Interference Tolerance

6.3.2.1 Base Transceiver Station

The receiver must be capable of operating at the specified BER in the presence of an adjacent channel interference signal that is equal in power to the desired signal, i.e. $C/I_{adj} = 0$ dB.

6.3.2.2 Subscriber Transceiver Station

The receiver should be capable of operating at the specified BER in the presence of an adjacent channel interference signal that is equal in power to the desired signal, i.e. $C/I_{adj} = 0$ dB.

6.3.3 Carrier Wave Interference Tolerance

6.3.3.1 Base Transceiver Station

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A CW interfere, at a level of +30 dB with respect to the wanted signal and at any frequency up to 60 GHz, excluding frequencies within ± 250% [or ± 500%] of the Occupied [channel] bandwidth centered around the centre frequency of the wanted signal, should not cause a degradation of more than 1 dB of the BER threshold.

6.3.3.2 Subscriber Transceiver Station

A CW interfere, at a level of +30 dB with respect to the wanted signal and at any frequency up to 60 GHz, excluding frequencies within 500% of the center frequency of the wanted signal, should not cause a degradation of more than 1 dB of the BER threshold.

7 Deployment & Co-ordination

The following paragraphs provide a recommended structure process to be used to co-ordinate deployment of BWA systems in order to minimize interference problems.

Note that national regulation and / or international agreements may impose tighter limits than the following and will take precedence in this case.

This methodology should facilitate identification of potential interference issues and should minimize the impact in many cases, but compliance with this process will not guarantee avoiding interference problems.

It is recommended that a similar methodology apply to both co-frequency/adjacent area situations as well as adjacent frequency/same area situations. In both cases, the psfd limit applies to co-frequency emissions within the victim's authorized band.

NOTE in the following, "coordination" as a minimum implies a simple assessment showing the likelihood of interference, AND it may imply a detailed bi-lateral negotiation between operators to mitigate problem areas for the benefit of both systems.

7.1 Co-Frequency / Adjacent Area

7.1.1 Methodology

Coordination is recommend between licensed service areas where both systems are operating co-channel, i.e. over the same BWA frequencies and where the service areas are close proximity

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e.g., the shortest distance between the respective service boundaries is less than[4] 60 km. The rationale for 60 km is given in Section 7.1.2. The operators are encouraged to arrive at mutually acceptable sharing agreements that would allow for the provision of service by each licensee within its service area to the maximum extent possible.

Under the circumstances where a sharing agreement between operators does not exist or has not been concluded, and whose service areas are in close proximity, the following coordination process should be employed <figure to be inserted>(see Figure or section ?)[refer to RA and IC process in Annex].

BWA operators should calculate the power spectral flux density (psfd) at their own service area boundary. Power spectral flux density (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, curvature of Earth. The psfd level at the service area boundry shall be the maximum value for elevation point up to 500m above local terrain elvation.No aggregation is needed, because principal interference processes are direct main beam to main beam coupling. Refer to the next section below for a rationale behind the psfd levels presented in this process.

The limits here refer to an operator's own service boundary, since that is known to the operator and will frequently be the same as the adjacent operator's service boundary. In cases where the two boundaries are separate (e.g., by a large lake), dialog between operators, as part of the coordination process, should investigate relaxing the limits by applying the limits at the adjacent service boundary. In cases where there is an intervening land mass (with no licensed operator) separating the two service areas, a similar relaxation could be applied, however in this case, caution is needed since both existing operators may have to re-engineer their systems, if a new licensee is awarded at a future time for this intervening land mass.

Deployment of facilities which generate a psfd less than or equal to -114 dBW/m^2 averaged over any 1 MHz at their own service area boundary are not subject to any coordination requirements. (It should be noted that the psfd values referred to in this section applies to systems operating in the 24,26,28 GHz frequency range. A table (Table 11 - **Maximum psfd Limits**), showing the corresponding psfd limits, is given below to address systems operating outside of this range.)

Table 11 - Maximum psfd Limits

Frequency Band	PSFD (dBW/MHz-m^2)
24,26,28 GHz	-114

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

38,42 GHz	-111

7.1.2 Co-ordination Trigger

As described above, distance is suggested as the first trigger mechanism for co-ordination between adjacent licensed operators. If the boundaries of two service areas are within 60 km of each other, then the co-ordination process is recommended.
The rationale for 60 km is based upon several considerations including radio horizon calculations, propagation effects, and power flux density levels (the latter is discussed in the next section).

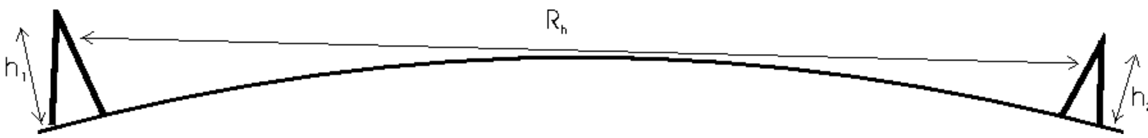

Figure 18 - Definition of Radio Horizon

The radio horizon, the maximum line-of-sight distance between two radios, is defined as:

$$R_h=4.12(\sqrt{h_1} + \sqrt{h_2}) \qquad (6)$$

where

R_h = Radio Horizon (km)

h_1 = Height of radio 1 above clutter (m)

h_2 = Height of radio 2 above clutter (m).

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

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

	Height of Radio 1 (m) above clutter								
Height of Radio 2 (m) above clutter	10	20	30	40	50	60	70	80	90

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

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

7.2 Same Area / Adjacent Frequency

To estimate potential interference into other BWA systems in the same area, it is necessary to estimate the Unwanted (Spurious and Out-of-Band) emissions (see Section 6.1.4) from one system, which are co-frequency with the another system operating in the same general area. It is recommended that around each base antenna, a map be drawn showing psfd contours where these out-of-band emissions are expected to exceed psfd levels. . These maps should be passed to any operator using those frequencies in the same area and the process as in Section or Figure [x]should be followed.
Note that if these out-of-band psfd contours extend beyond the service area, then the process in section [x] should also be undertaken for adjacent areas.
It is recommended that any operator receiving such plots should:

- Reciprocally offer similar plots of his own emissions to the other operator
- Carefully assess the plots received to determine the severity of any interference
- Initiate a dialog with the other operator to minimize any impacts.

NOTE it is likely that, unless there is significant angular, time, frequency or distance separation between transmitters and receivers, there will be an area of interference close to a transmitter.

As stated in Recommendation 8, deployments will usually need one guard channel between nearby transmitters. Where administrations do not set aside guard channels, the affected operators will need to reach agreement on how the guard channel is apportioned between them

7.3 Use of Power Spectral Flux Density (psfd) as a Coexistence Metric

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

In Annex B - a typical psfd calculation is shown at the frequency of 28 and 38 GHz.

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

7.4 Deployment Procedure

This section describes a process for an operator to follow in deploying a BWA system to promote coexistence. The process is essentially a 'turn-on' procedural list that should be followed before the operators activate their transmitter(s) to ensure they do not inadvertently interfere with or cause performance degradation to an existing system operating either co-located or in an adjacent area. The operator is highly encouraged to communicate with other known operators who may be potentially affected, since the slightest interference could severely affect their business.

The 'turn on' procedure is as follows:

Follow the coordination procedure described above and where applicable, take the necessary mitigation steps accordingly.

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From a rooftop with good visibility over the target cell area, scan the surroundings with a radio detector and spectrum analyzer to determine if any interference is present that may adversely affect the performance of the system to be deployed.
Ensure the antennas are properly installed in terms of main beam direction (AZ and El) and polarization (for the latter, labeling on the antenna to clearly indicate polarization is highly recommended). The antennas should also be sufficiently mechanically supported to withstand the worst case local wind conditions such that the antennas only deviate from their original alignment to within [+/- 0.5] degrees.
Before turning on the transmitter verify the proper tests have been performed to ensure EIRP and OOB emissions fall within the regulated/ recommended limits.
Verify the transmitter EIRP does not exceed safety limits as specified by local regulations.
Verify the transmitter or its IF cables do not interfere with IF cables or receivers from other co-located systems.
Verify the transmitter will automatically turn off in the event that it becomes rogue i.e. it loses lock and begins to transmit randomly in power and spectrum.

8 Interference and Propagation Evaluation/Examples of coexistence in a PMP environment

8.1 Guidelines for Geographical and Frequency Spacing between BWA systems

8.1.1 Summary

This section provides guidelines for geographical and frequency spacings of BWA systems that would otherwise mutually interfere. The guidelines are not meant to replace the co-ordination process described in section [7]. However, in many (probably most) cases, by following these guidelines, satisfactory psfd levels will be achieved at system boundaries. The information is therefore valuable as a first step in planning the deployment of systems.

The actual psfd levels can then be calculated or measured, as appropriate, and any adjustments to system layout can then be made. These should be relatively small, except in unusual cases.

8.1.2 Interference Mechanisms

Various interference mechanisms can reduce the performance of BWA systems. Although intra – system 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, including the decision as to what constitutes an acceptable maximum level. Thus, only inter-system interference mechanisms are considered, where inter-operator co-ordination may have to be considered.

In each frequency band assigned for BWA use, there may be different types of systems deployed, some conforming to 802.16.1 standards and some designed to other specifications. Therefore, we consider a wide range of possibilities in determining the likely interference levels and methods for reduction to acceptable levels.

There are two main scenarios, each with several variants:

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

The various potential CS-TS-RS interference paths must be considered to determine how much interference will occur. Between any two systems, there may be several interference mechanisms 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.

A number of techniques have been used to estimate inter- system interference:
Worst case analysis
Interference Area method
Monte Carlo simulations

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

8.1.3 Worst-case analysis

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

8.1.4 Simulations

There are many cases where a simple worst - case analysis is of limited use. Where there are many possible interference paths between a particular type of interfere and the associated victim stations, the worst case could be very severe but may also be very improbable. Planning on the basis of the worst case would then be unrealistic. An example is the interference between subscriber stations of different operators in the same geographical area. Most interference will be negligible but a certain small proportion of cases could have very high interference levels.

Monte - Carlo simulations provide a means of assessing the probability of occurrence of a range of interference levels at victim stations. The recommended geographical or frequency spacing is

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then a compromise, in which an acceptably small proportion of cases suffer interference above the recommended limit (e.g. 1% of randomly positioned subscribers would suffer interference above the desired level).

A model of an interference scenario is created using realistic parameters, in which the placement of BWA stations (usually the TS) can be randomly varied. Other randomly varied parameters may be included, such as buildings and terrain factors. The simulation is run many times and the results plotted as a probability distribution.

8.1.5 Interference Area (IA) method

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

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

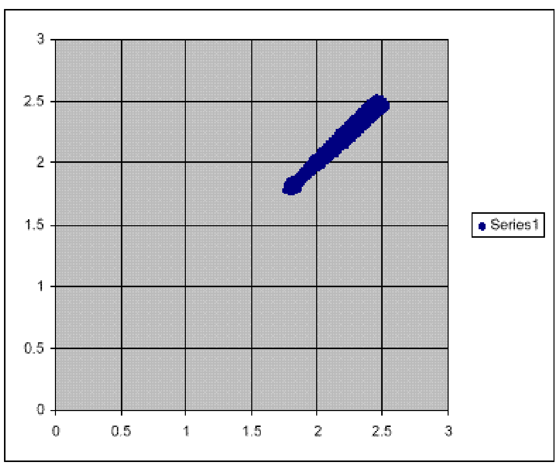

Figure 19 - Example of Interference Area diagram (CS-TS adjacent area case)

8.1.6 ISOP (Interference Scenario Occurrence Probability)

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Although not used in this document, the concept of ISOP may be interesting in some cases. The ISOP analysis is an extension of the IA method, in which a calculation is made of the probability that at least one victim terminal 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 the ISOP method can be found in a draft CEPT/ERC technical report SE19(99)195, due for completion and publication during 2000.

Table 13 - Summary of the simulations and calculations

< last column will not be included in final version>

Path (note 1)	FDD or TDD	Scenario	Method	Spacing for acceptable Performance	Source of analysis
Sub to Hub	FDD/TDD	Adjacent Area, same frequency	Monte Carlo simulation	40km CS-CS	Wavtrace (GJG)
Hub to Sub	FDD/TDD	Same area Adjacent channel(s)	Monte Carlo simulation	1 guard channel (note 2)	Wavtrace (GJG)
Sub to Hub	FDD/TDD	Same area, adjacent frequency	Monte Carlo simulation	1 guard channel (note 2)	Wavtrace (GJG)
Hub to Sub	FDD/TDD	Same area Adjacent channel	Interference Area (IA)	1 guard channel = 0.5-2% IA (note 2)	TTPCom (JH)
Sub to Sub	TDD	Adjacent channel	Monte Carlo simulation	1 guard channel (note 2)	TTPCom (JH)
Sub to Sub	TDD	Co-channel	Monte Carlo simulation	Low probability if CS-CS >35km	TTPCom (JH)
Sub to Hub	TDD/FDD	Co-channel	Interference Area (IA)	35km CS-CS	TTPCom (JH)
Hub to Hub (multiple interferes)	TDD-FDD	Co-channel	Monte Carlo simulation	60km (note 3)	Crosspan (JLL)
Mesh to	TDD/FDD	Adjacent	Monte –	12km	Radiant

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PMP Hub		area, same frequency	Carlo Simulation	CS to mesh edge	
Mesh to PMP Sub	TDD/FDD	Adjacent area, same frequency	Monte – Carlo Simulation	Low probability if mesh edge to CS >12km	Radiant (PW)
Mesh to PMP Hub	TDD/FDD	Same area, adjacent frequency	Monte – Carlo Simulation	1 guard channel (Note 4)	Radiant (PW)
Mesh to PMP Sub	TDD/FDD	Same area, adjacent frequency	Monte – Carlo Simulation	1 guard channel (Note 4)	Radiant (PW)

Note 1: All scenarios represent interference paths between two different PMP systems unless otherwise stated.

Note 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 sizes are different, the guard channel size should be equal to that of the wider channel system.

Note 3: The results from the multiple CS interference simulation are based on an adverse terrain assumption and on the use of omni directional hub antennas. The victim hub is assumed to be at a high location, with clear line of sight to all interfering hubs. Results taking account of terrain and building losses and sectored hub antennas are for future analysis.

Note 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.

8.1.7 Variables

In the simulations, a number of parameters have been varied in order to test the sensitivity of the results to critical aspects of system design. In particular, antennas with various RPEs have been evaluated. It is concluded that, although many results are improved by use of more tightly specified antennas, the absolute value (probability of interference) tends to be quite low with all the antennas considered. On this basis, good practice is to choose the best antenna possible, consistent with system economics.

In some configurations, the intra system interference considerations will dominate the decision on antenna RPEs. Effective frequency re-use between cells will demand the use of antennas that can provide satisfactory inter-system interference levels.

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8.1.8 Results of the analysis

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

8.1.9 Co-channel case

8.1.9.1 Hub to Hub co-polar, single and multiple interferes

This scenario only occurs where the victim hub receiver is co-channel to the interfering hub transmitter. The hub to hub 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 re-pointing the hub or by changing frequency can be very disruptive to a system. Therefore, a relatively "safe" value should be applied to co- channel, co-polar geographical spacing. Shorter distances are possible but will increase the probability of interference. Therefore it is recommended that these be verified by more detailed analysis.

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

The results for this case are derived from worst-case analysis (for a single interfere and a typical set of system parameters) and from simulation. This analysis has used parameters that are typical of BWA systems.
For systems with multiple hubs, 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 interfere.

8.1.9.2 Subscriber to Hub, co – channel case

In this case, single and multiple subscribers must be considered. Dependent on the system design, the number of subscribers which transmit at any one time may be low (or only one) from a given cell sector. However, interference can often arise from several cells, especially when rain fading occurs selectively (i.e. where a localized storm cell attenuates some radio paths but not others).
In the case of mesh systems, there may be several interferes on a given channel, although only a small number will transmit simultaneously and very few will be visible at a particular hub. Simulation (Monte Carlo modeling) is needed to analyze this case of multiple interferes.

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8.1.9.3 Subscriber to subscriber, co-channel case

Interference between subscribers in adjacent areas has, in general, a low probability of occurrence. In PMP systems, it usually occurs in specific areas. Its level could be low or high, depending on circumstances. If co-channel PMP cells are at or beyond the minimum recommended "safe" distance, subscriber 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 hub (due to the higher gain antenna of the subscriber station).

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

8.1.10 Overlapping Area Case

8.1.10.1 Hub to hub interference

[TBD]

8.1.10.2 Sub to hub interference

In PMP systems, this type of interference is evaluated by use of a simulation program. It is clear that an interfering TS could be relatively close to a victim CS but the level of interference depends on the relative locations of the hubs of the two systems (which affects the antenna pointing direction) on the use of ATPC and on possible differential rain fading. This case is analyzed in [xx] and shows that a single guard channel between systems will in general be a good guideline for uncoordinated deployment.
Where the interfere is a mesh system, the antenna pointing directions are more random and possible multiple interferes have to be considered. An analysis of this situation is in [xx] and shows that the same one channel guard band is a good guideline for uncoordinated deployment.

8.1.10.3 Subscriber to subscriber, same area case

This problem has to be analyzed by use of simulations (Monte Carlo modeling). In general, the probability of interference occurring is low but, when it does occur, the level can be high. Unlike the hub to subscriber case, the high levels of interference are not in predictable parts of the cell(s). Mitigation is by use of guard bands, improved antennas and (in mesh systems) by re-routing so as to avoid the worst pointing directions of antennas.
An analysis of this case can be found in [xx] for the PMP case and in [xx] for the mesh-PMP case.

9 Mitigation Techniques

9.1 General

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

In general, analyses to evaluate the potential for interference as well as any possible mitigation solution should be performed prior to systems implementation. Coordination with adjacent operators could significantly lower the potential for interference.

9.2 Frequency Band Plans

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

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

FDD base stations that transmit in the same sub-band do not interfere with each other.

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 and must be considered an absolute last resort, where all other remedial opportunities have been completely exhausted between the licensed operators.

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

9.3 Service Area Demarcation

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

9.4 Separation distance/Power

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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 interfere and the victim cannot be increased, then the transmitter power can be lowered to achieve the same effect. However, both 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 STSs within a cell or sector in a given service area to improve the signal to interference level into the base station receiver. Operating the STSs 'hot' at all times may help to address the adjacent area interference, however, it may introduce other interference scenarios that are equally undesirable, therefore, caution should be exercised if this approach is taken.

When tackling co-existence between systems operating in adjacent frequency blocks in the same or overlapping areas similar operating EIRP levels help to facilitate co-existence between interfering base stations and victim terminal stations

In addition to the Recommendation (see Recommendation 11 in Section 4.1) for upstream power control, downstream power control is an additional, optional feature that would reduce interference from BTSs.

9.5 Co-siting of Base Stations

When tackling co-existence between FDD systems operating in adjacent frequency blocks in the same or overlapping areas with defined uplink and downlink frequency bands, co-siting of Base Station transmitters help to facilitate co-existence (Ref: 802.16l-00/07r2 clause 4.3 and 8.1.1)

9.6 Co-existence with PTP Systems

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

9.7 Antennas

9.7.1 Antenna-to-Antenna Isolation

In practice, sector antennas are being co-located that are directed to the same sector. Such co-location involves two primary configurations. In one case, there are multiple antennas mounted at the same site on the same mounting structure that are directed to the same sector angle. In the second case, there are multiple antennas mounted at the same site on different mounting structures that are directed to the same sector.

Antenna-to-antenna isolation is dependent on factors like site location, mounting configurations, and other system level issues. Even with seemingly uncontrollable factors, there is a need for isolation between the antennas directed to the same sector. For guidance, the antenna-to-antenna isolation for antennas, which are co-pointed to the same sector with sector sizes of 90° and less should be minimally 60 dB.

9.7.2 Orientation

In certain system deployments, sectorized antennae will be 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 before with separation distance, although to a lesser degree, this mitigation technique may not be practical in certain deployment scenarios.

9.7.3 Tilting

Similar to 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, hence reducing interference to the victim receiver. However, in some systems, the downtilt range could be quite limited either due to technical reasons, or economic reasons, rendering this technique impractical.

9.7.4 Directivity

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

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

9.7.5 Antenna Heights

In circumstances where adjacent licensed base stations are relatively close to each other, another possible technique to avoid interference is to place the base station antennae at lower heights to indirectly create LOS blockages to neighboring base stations. This solution will not be practical in many cases, as it will significantly cause a reduction in coverage area (i.e. mini-cell), however, under certain conditions, it may be the best option available for addressing the interference issue.

9.7.6 Future Schemes

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Future schemes may be available such as adaptive arrays or beam-steering antennas, which 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, represents another possible approach towards addressing interference.

9.7.7 Polarization

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

9.8 Blockage

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

9.9 Signal Processing

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

9.10 EMI/EMC

There are many undesired signals, which will affect the operation of a system. There are two major sources of EMI. One is the natural phenomena (e.g. lightning) and the other is the man made EMI, which consists of intentional (e.g., RF transmitters) and unintentional (e.g., radiated spurious) sources.

9.10.1 Natural Phenomena

Lightning stroke to a tower can be very destructive to a transmitter/receiver if the proper precautions are not taken. Due to the nature of lightning is random and unpredictable, the following techniques do not prevent no failures or disturbances, but will minimize the potential damage.

Proposal 1: Installation of lightning arrestors is encouraged at the entry point in the equipment room/ building and at any outdoor electronic unit.

Proposal 2: Grounding of as many points as possible on the transmission line is recommended. The main points of interest are near the bottom of the tower before entering the equipment room/ building, and at the top of the tower near the outdoor electronic unit. It has been considered that grounding the coax cable every 50 feet will mitigate voltage potential differences.

9.10.2 Man Made EMI

The two man made EMI effects can be avoided by using good design rules to comply with regulatory requirements globally in the design of the product. Today, with most of the PCS, cellular, etc. operating in a co-located area, it would be necessary to achieve the most stringent requirements for immunity stated in most of the regulatory requirements. The products should be able to achieve the emission and immunity requirements within its specific country, but also, in the environment that the product is intended to be used in.

Proposal 3: The product should be able to operate according to the ETSI standard EN 300 385 (new number EN 301 489-4) ' EMC standard for fixed radio links and ancillary equipment' and the Bellcore GR-1089-CORE ' Electromagnetic Compatibility and Electrical Safety – Generic Criteria for Network Telecommunications Equipment '. This will reduce the risk of EMI problems in an Intra-system environment and also some of the unintentional radiators (e.g. TVs, radio receivers, test instruments, etc.)

Proposal 4: In a BWA Inter-system environment, the system many have to be located at a minimum distance from the other operator's equipment, to reduce interference to an acceptable level.

Proposal 5: The product should be able to operate with a field strength of 10V/m in the PCS and Cellular bands. This would reduce interference with mobile phones at a distance of approximately 24 inches [see Figure 20 - **Approximate Field Strength of a Cellular Phone (P=600mW)**].

Figure 20 - Approximate Field Strength of a Cellular Phone (P=600mW)

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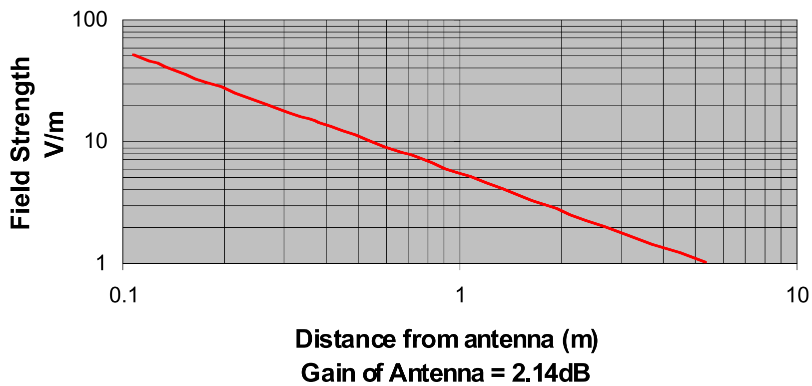

Proposal 6: If co-locating the system with another intentional radiator (e.g. PCS, Cellular, etc.), it is extremely important to determine what is the field strength within that environment. Take the proper precautions, which may involve better shielding, (cable shielding, cabinet shielding, etc) placement of antennas, use of notch or bandpass filters, etc.

9.11 Receiver Sensitivity Degradation Tolerance

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

$$\Sigma I = P_{\text{intra}} + P_{\text{coex.}} \qquad (5)$$

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

9.12 Subscriber TX lock to prevent transmissions when no received signal present

In the absence of a correctly received downstream signal, the subscriber transmitter should be disabled. This is intended to prevent unwanted transmission from creating interference that would prevent normal system operation due to antenna mis-alignment. The subscriber should continuously monitor the received downstream signal and if a loss of received signal is detected, no further transmissions are 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 subscriber a mechanism to notify the base station of the system fault.

9.12.1 Fail-safe

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

TX PLL lock status
Power Amplifier drain voltage/current
Main power supply
Microprocessor watchdog

The implementation of which items to monitor and preventive and/or corrective actions are considered to be vendor specific and not intended to increase system cost. However, the intent is to prevent transmissions, which may result in system interference due to individual STS failures.

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Annex A - Test and Measurement / Hardware parameter summary
[informative]

A.1 Testing of Unwanted Emissions

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

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

A.1.1 Methodology

Single-carrier and multi-carrier requirements are described below. If multicarrier operations are intended, then both requirements must be met. "Multicarrier" refers to multiple independent signals (QAM, QPSK, …) and does NOT refer to techniques such as OFDM.

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

Table A.1 - Minimum Separation between Actual and Virtual Band Edge for Different Bands

Band	Minimum Separation between Actual and Virtual Block Edge
24/26 GHz	10 MHz
28 GHz	40 MHz
38 GHz	10 MHz

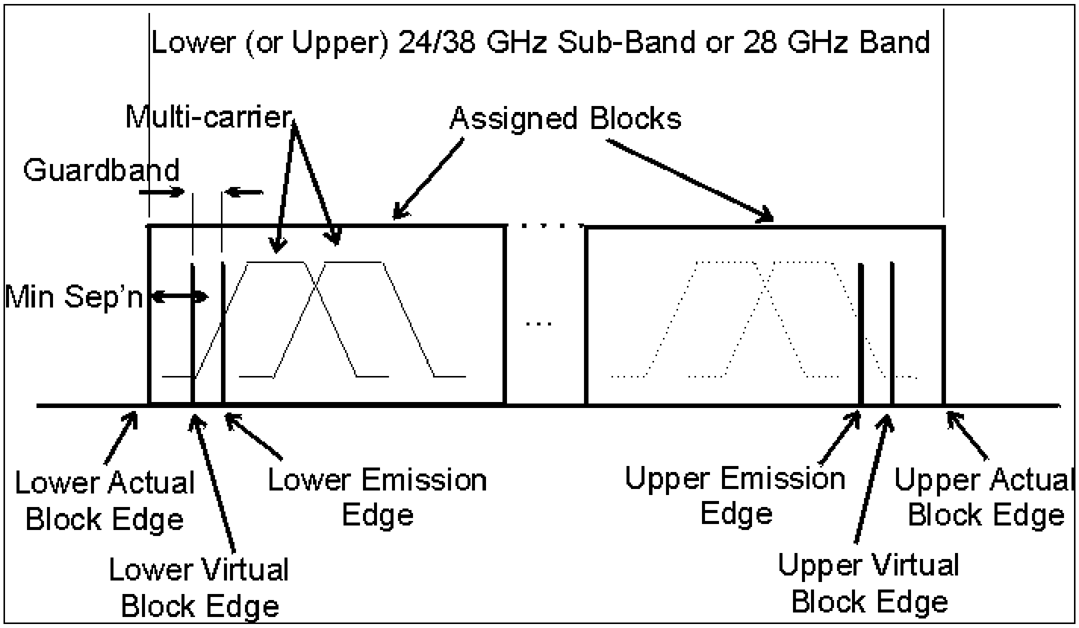

Figure A.1 - Band Edge Definitions

Unwanted emissions should be measured when the transmitter is operating at the manufacturer's rated power and modulated with signals representative of those encountered in a real system operation. Unwanted emissions should be measured at the output of the final amplifier stage or referenced to that point. The measurement can be done at the transmitter's antenna connector as long as there is no frequency combiner in the equipment under test. It is important however that the point of measurement for this test be the same as the one used for the output power test. The point of measurement and the *occupied* bandwidth (B_o) should be stated in the test report Single-carrier and multi-carrier requirements are described below. If multicarrier operations are intended, then both requirements must be met. "Multicarrier" refers to multiple independent signals (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 section 6.1.4 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 5th harmonic of the highest frequency generated or used, without exceeding 40 GHz.

A.1.2 Single carrier test

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

The user manual should contain instructions, such as details on the minimum guardband sizes required to ensure that the radios remain compliant to the certification process.
It is to be noted that the regulations may permit licensees to have more than one frequency block for their systems. Equipment intended to have an occupied bandwidth wider than one frequency block per carrier should be tested using such a wideband test signal for the section 6.1.4.1 requirement.

A.1.3 Multi-carrier test.

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

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

Notwithstanding the requirements in the TableA.1 "Minimum Separation between Actual and Virtual Block Edge", any equipment which uses the complete block or multiple blocks for a single licensee can include the attenuating effect of any RF filters in the transmitter design within the multi-carrier test, in which case the Virtual and Actual block edge frequencies will be the same.

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

A.2 Measuring Frequency Stability.

As discussed in section 3.1.3, the RF carrier frequency should not depart from the reference frequency (reference frequency is the frequency at 20^{o}C and rated supply voltage) in excess of +10 ppm. The RF frequency of the transmitter should be measured:

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(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 +20º C .

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

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Annex B - Power Spectral Flux Density (psfd) calculations

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

$$N_o = 10Log(kT_o) + N_F \quad (7)$$

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

where

No = Receiver thermal noise power spectral density (dBW/MHz);
kT_o = Equipartition Law (-144 dBW/MHz);
N_F = Receiver noise figure (6 dB).

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

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

$$psfd = \frac{\Pr}{Ae} = \frac{\Pr}{\lambda^2 \frac{G}{4\pi}} = \Pr - 10Log(\lambda^2) - G + 10Log(4\pi) \quad (8)$$

where

Pr = interference power level into receiver (-144 dBW/MHz);
Ae = effective antenna aperture;
λ = wavelength;
G = antenna gain.

20 – 30 GHz

Assuming an operating frequency of 28 GHz (λ=.011m) and a typical base station antenna gain of 20 dBi, then the tolerable interference level is given as:

$Psfd_{BTS}$ = -144 - 10Log($.011^2$) – 20 + 10 Log(4π) = -144 + 39 – 20 + 11
= -114 dBW/MHz-m^2

Note that the base station receiver is considered only in this analysis (not the subscriber). This is primarily due to the fact that BTS' are typically located on high buildings/structures with omni directional coverage which tend to increase their probability of achieving line of sight (LOS) to adjacent licensed area transmitters. Subscribers, on the other hand, tend to be situated at low altitudes (~15 m) which significantly reduces the probability of LOS (due to obstacles/clutter) to adjacent area systems. Furthermore, subscribers have highly directional antennas (narrow

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beamwidths) which further reduces the probability that they will align with an interference source from an adjacent area.

The –114 dBW/MHz-m^2 represents psfd A in the 20-30 GHz range of the co-ordination process described above.

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

$$psfd_{victim} = P_{TX} + G_{TX} - 10\log(4\pi) - 20\log(R) - A_{losses} \quad (9)$$

where
P_{TX} = transmitter power (- 25 dBW/MHz)
G_{TX} = transmitter antenna gain in the direction of the victim receiver (18 dBi)
R = range (60000 m)
A_{losses} = atmospheric losses, ~ 0.1 dB/km

The values given in brackets represent typical BWA parameters.

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

$$psfd_{victim} = -25 + 18 - 10\log(4\pi) - 20\log(60000) - 60*.1 = -120 \text{ dBW/MHz-m}^2$$

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

30 – 40 GHz

The psfd limits for the 30-40 GHz frequency range were derived in a similar manner.

The following assumptions apply:

BTS
Gtx=Grx=14 dBi

STS
Gtx=Grx=36 dBi

Point-to-point radio
Grx=44 dBi

Receiver noise floor= -138 dBW/MHz

The following formula is used to calculate psfd at the antenna aperture:

$$psfd = \frac{P_r}{A_e} = \frac{P_r}{\lambda^2 \frac{G_r}{4\pi}}$$

where

$\lambda = c / f = 3x10^8 / 38x10^9$

P_r = interference objective

G_r = receive antenna gain

The following is a sample calculation for a point-to-point receiver with an antenna gain of 44 dBi given the interference objective for the point-to-point radio is assumed to be 6 dB below the noise floor, which is equivalent to P_{r1} = –144 dBW/MHz.:

$Psfd_1 = P_{r1} + 10 \log (4\pi) – 20 \log (\lambda) - G_r$
= -144 + 11 + 42 – 44
= -135 dBW/m^2 in any 1 MHz

However, in order to minimize the number of coordination, and given the low probability of main-beam to main-beam coupling, a further 10 dB of interference can be tolerated. This brings the objective to P_{r2}= -134 dBW/MHz, the psfd may then be recalculated as follows:

$Psfd_2 = P_{r2} + 10 \log (4\pi) – 20 \log (\lambda) - G_r$
= -134 + 11 + 42 – 44
= -125 dBW/m^2 in any 1 MHz

The table below summarizes the resulting psfd limits for each radio entity:

Radio Entity	**Interference objective (dBW/MHz)**	**PSFD A (dBW/m^2 in any 1 MHz)**	**PSFD B (dBW/m^2 in any 1 MHz)**
BTS	-144	-105	-85
STS	-144	-127	-107
Point-to-Point	-144	-135	-115
	-134	-125	-105

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Annex C - Description of Calculations and Simulation Methods

Subscriber to Hub, Adjacent area, same frequency

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

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

Simulation Model (TS to CS)

Figure [x] illustrates the simulation model. Two co-channel sectors are exposed to each other across a boundary.

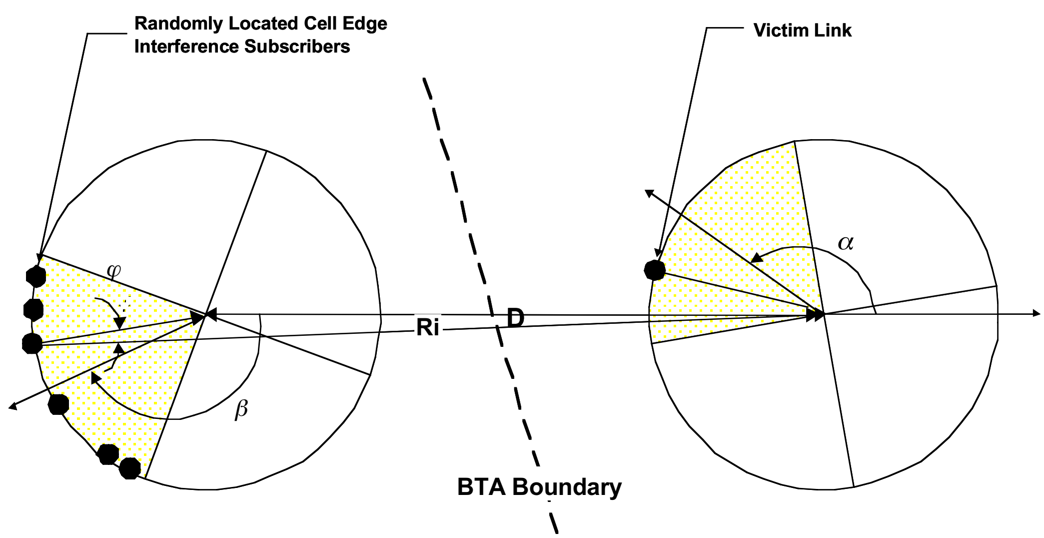

Fig [x]

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

As the operator assignments for sector location are assumed to be uncoordinated, the victim link CS boresight angle is set at some value α and the interference CS boresight is set at some value β. Angle α establishes the RPE antenna discrimination to be expected from the victim CS link. To complete a simulation, both CS boresight angles are independently incremented in 5 degree spin intervals. For each spin, the worst C/I estimate is computed from the 20 interference

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locations and entered into a database. For each CS spin, the locations of the interference TS positions are modified by changing the random number seed. A simulation, parameterized against D, thus consists of 5184 interference level estimates. These values are sorted to provide a cumulative distribution function (CDF) estimate of pfd vs D.

Simulation Results

The main conclusions from this analysis are:

at distance D = 40km or greater, the cumulative distribution curves show negligible exposures above the required pfd threshold. This is therefore a satisfactory preliminary planning value for hub to hub spacing with no co-ordination.

ETSI CS1 antennas (sectored hub antennas) show much more rapid increase of pfd values above the threshold than other types. These antennas should therefore be used with care and antennas with better sidelobe performance are generally preferred.

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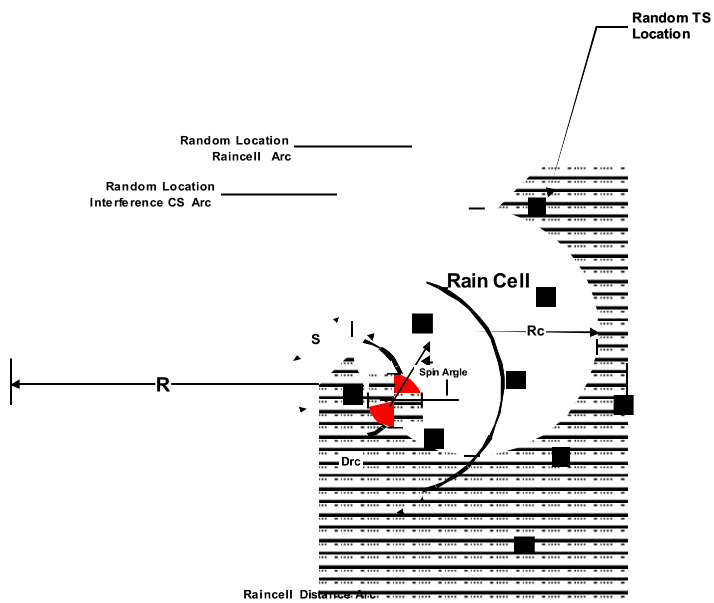
Hub to Subscriber (CS to CS), same area, adjacent frequency

These simulations address the case of multiple operators deployed in a given geographical area that are employing adjacent frequencies. In this case, the most serious conflicts occur when two operators have adjacent carriers of the same polarization. The most severe deployments are thus represented by cell overlays involving VB/VD or HB/HD. 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 20dB (adjacent channel operaytion) 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.

Simulation Model (CS to TS)

Figure [9] illustrates the simulation model. The interference CS is placed in the victim sector at some parameterized distance S between the hub centers.



Relative angular position of the interference CS is set random for each rotational spin of sector alignments. As the interference CS is always deemed to be within the victim sector, only the

sector alignment of the interference CS needs to be varied. Spin increments were taken at 5 degrees.
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 some one victim link experiences the full rain attenuation loss, D_{rc} is restricted to be within the range of 1.2 km to 2.4 km. A worst case value for D_{rc} would tend to be 1.2 km. At this distance, the rain cell just touches the victim sector, thus maximizing the number of TS locations that experience significant rain loss.
For each rotational spin of the interference CS, the angular position of the rain cell is randomized. Angular rotation is restricted to be within +/- 45 degrees, 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 geometry and rain loss procedure described in Section 3.0. Victim signal levels are computed based on the transmission parameters, link distance and rain loss. Interference signal levels are similarly computed but with the inclusion of antenna angular discrimination, relative frequency polarization and NFD. A single interference computation accounts for the contribution of each of the four CS sectors and each spin represents 20 independent C/I estimates. Thus a simulation is represented by 1440 C/I estimates. These are sorted and employed to develop a CDF for C/I at given values for S and D_{rc}.

Simulation results
The results for adjacent channel operation, with each of the antenna types considered, is unsatisfactory, with many exposures below the required C/I ratio. With a single (in this case 28MHz) guard channel, the proportion of exposures below the required C/I ration is very low. Thus, a single guard channel is satisfactory as an initial planning guide to mitigate CS to TS.

The results were not found to be sensitive to antenna RPE, except at very high values of C/I.

TS to CS interference must also be considered in the final choice of guard bands between systems operating in the same area.

Further details of this simulation can be found in IEEE 802.16.Xc-00/NNr0 (ref.[ ])

Same Area/Adjacent Frequency (TS to CS)

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

The system frequency and polarization model is identical to that of Figure [xx] and the simulation model employs the same methodology as described in Section [5.2.1] with ATPC now included.

Simulation Model (TS to CS)

It is now convenient to consider the victim CS to be as illustrated on Figure [xxx]. The rain loss of each of the 20 interference TS links is computed based on their exposure distance within the rain cell. The TX power of each interference TS is then ATPC adjusted to ensure that its combined distance and rain loss signal level suppression is such that it meets margin objectives. The signal level of each interference path into the victim CS is then computed based on the transmission criteria of the link.

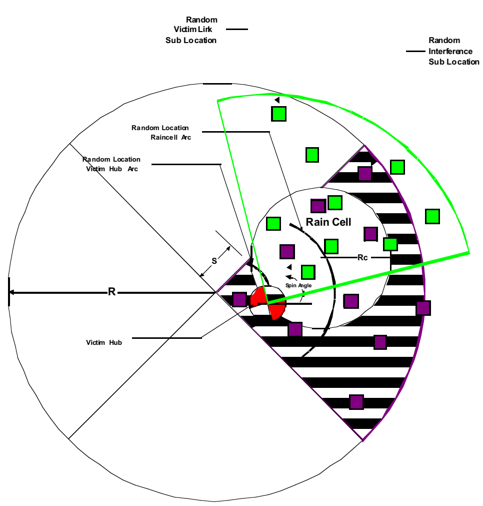


Fig xxx

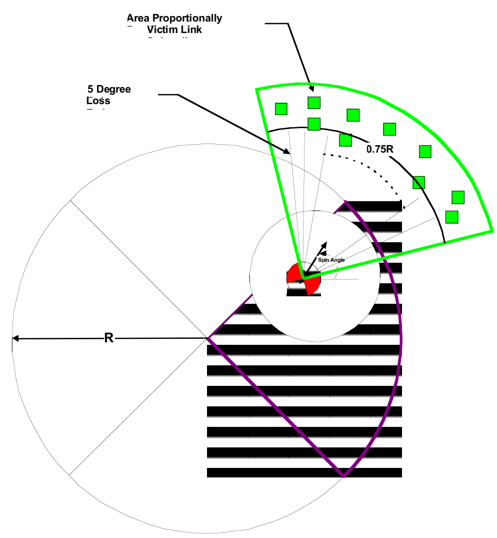


Fig xxxx

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

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

Simulation results
As with the CS to TS case, adjacent channel operation was found to be unsatisfactory, with many exposures suffering a C/I below the required limit. Similarly, a single guard channel reduces interference to an acceptable level.

Antenna RPEs have some impact on the results but are not a controlling factor.

CS to TS, Same area, adjacent channel, Interference Area method
This simulation derives the Interference Area (IA) for systems operating in the same area. It applies to FDD and TDD systems. The Interference Area (IA) is the proportion of the sector area where interference is above the target threshold, equivalent to the probability that a TS placed at random will experience interference above the threshold.

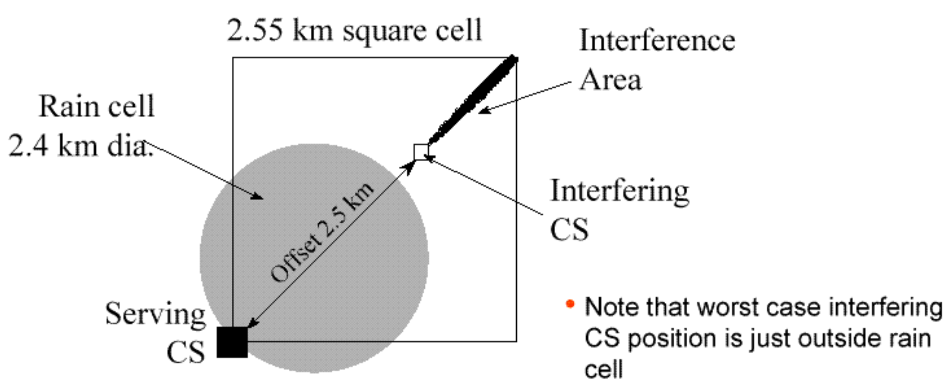


Fig. [y]

Analysis shows that the worst case is where the interfering CS is spaced approximately [0.6] times the cell diagonal away from the serving CS and when a rain cell in the most adverse position reduces the wanted signal. This is illustrated in fig. [y]

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

Simulation Results
For a single channel guard band, in all cases the Interference Area is relatively small and its location is predictable. Typically, it occurs in the “shadow” of the interfering CS and is a narrow

area following the cell diagonal and ending at or inside the cell boundary. The exact shape depends on the choice of TS antenna (smaller with a better antenna). For the parameters chosen, the IA was in the range 0.5% - 2%. Within the IA, the interference level can vary from a level that degrades performance to one which is unworkable. In the absence of rain fading, the IA is significantly reduced.

TS to TS, same area, adjacent channel, TDD only

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

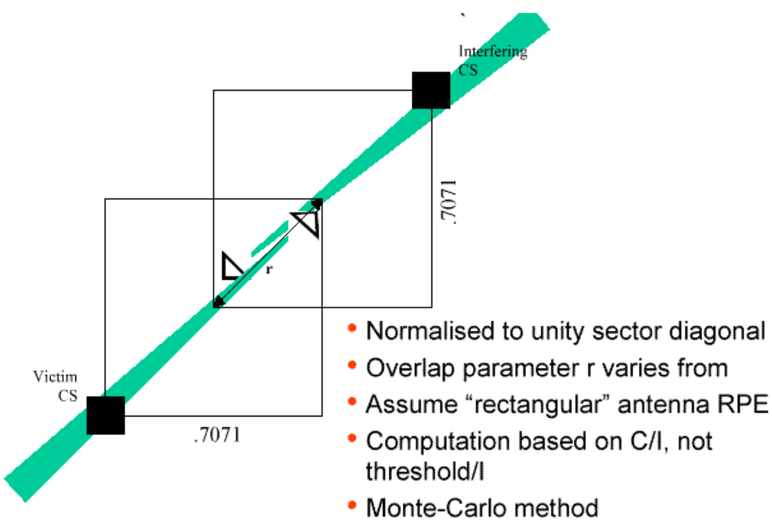


Fig [yy]

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

Simulation results
The C/I ratio probability distribution curves, adjusted for system factors including the NFD (Net Filter Discrimination) for one guard channel between systems, show the following results:

For small overlap values, the C/I ratio can be low but the probability is also very low

The maximum probability of conflict occurs at an overlap value of r=2, where the probability rises to approaching 10%. However, the C/I ratio is then at an acceptable level

Rain fading has a neutral or beneficial effect.

TS to TS, co – channel, adjacent area (TDD)
This simulation computes the C/I ratio at a victim TS, the interference arising from another TS in a cell in an adjacent area. The interfering and victim antennas are directional. Wanted and interfering cells may partly or wholly overlap. The geometry is similar to that shown in fig [yy] for the TS to TS same area case, but with larger values of cell offset.

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

Simulation results
The C/I probability curves show that at overlap values of as little as r = 5, the C/I values reach acceptable levels and the probability of the highest values is still very low. This corresponds to a distance which is lower than that required to reduce CS – CS or CS – TS interference to an acceptable level.
It is concluded that TS to Ts interference is not the limiting case for adjacent area co-channel operation

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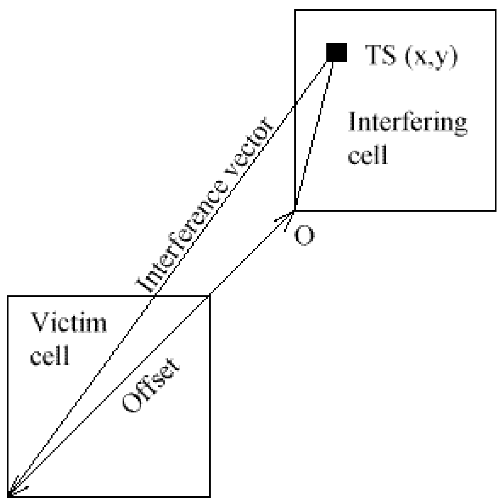
TS to CS, co- channel, adjacent area

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



- Limiting case for FDD cell spacing
- Based on adjacent channel Monte Carlo method
- Allows for atmospheric attenuation and uplink ATPC
- Atm = 0.21 dB/km
- ATPC = 15 dB reduction below full power at cell edge
- Antenna A: ETSI TS1
- Antenna C: TM4069

Fig. [yyy]

Simulation method

The Interference Area (IA) is constructed in a similar way to the Hub to sub same area case. In this case, it is the interfering TS that lies in the Interference Area, the victim being the distant hub. Atmospheric attenuation and uplink ATPC are taken into account. Additionally, the effect of using different TS antennas is calculated. Charts are also constructed of the probability of interference against the cell offset value

Simulation results

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

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

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

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CS to CS, co-channel, multiple interferers

[TBD]

Simulation method

[TBD]

Simulation results

[TBD]

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Mesh to PMP CS, co channel, adjacent area

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

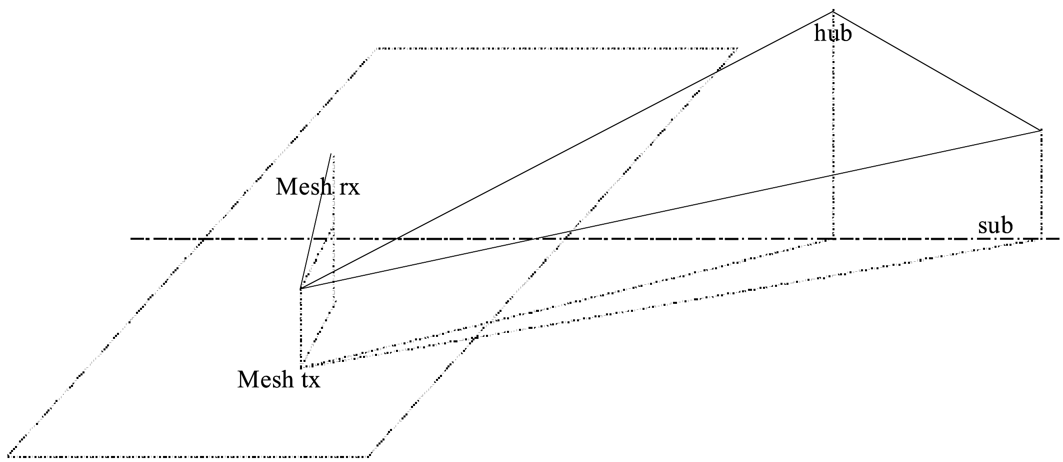

Fig. [z]

Simulation method

The main attributes of the model are:
Monte-Carlo simulation with realistic MP-MP system parameters.
Line-of-sight propagation probabilities calculated from Rayleigh roof height distribution function as per CRABS WG3 report D3P1B [ref.tba]
Interfering power summed at PMP base or subscriber using full 3D geometry to compute distances and angles between lines of sight and antenna bore-sights.
Effect of Automatic Power Control granularity (ATPC) included.
PMP RPE's for 24-28GHz band to EN 301 215-2 V1.1.1 [ref. tba] with BS elevation profile ignored for realistic worst case.
MP-MP antenna RPE model for 24-28GHz band simulates an illuminated aperture with side-lobes to EN 301 215 V1.1.1 [ref. tba].
Atmospheric attenuation to ITU-R P.676-3 [ref. tba]
Rain attenuation to ITU-R P.840-2 [ref. tba].
Dry, storm and frontal weather patterns considered.

The interference target maximum level in the model is –114dbm/MHz measured at the victim receiver input. A large number of trial runs of the simulator tool (typically 10,000) are used to generate a histogram of interfering signal against probability of occurrence. The deduced minimum spacing is based on the worst case value of interference. In practice this has a very low probability so that the results indicated below are conservative.

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 the RPE. For typical system parameters quite modest geographical spacing is possible. For example, a hub which is 50m above ground level will require a geographical spacing of only 12km from the mesh edge (service area boundary of the mesh, assuming it is populated right up to the boundary). Most trial configurations gave much better results (lower interference) so that by careful deployment, lower spacing is practical.

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

The guideline for PMP to PMP network separation [40km] will be conservative for a mesh deployment. A reduced spacing will be possible without co-ordination and a further reduction will be possible by co-ordinating with neighbouring operators.

Mesh to PMP TS, co channel, adjacent area

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

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

Simulation results
For all practical hub (CS) locations, TS heights and locations in the PMP cell, it was found that interference levels were lower than those received by the corresponding hub (CS). Thus, the controlling factor is the mesh to hub spacing. At the 12 km spacing determined for mesh to 50m high hub, all TS interference is below the target level of –114dBm/ MHz, for any randomly selected mesh configuration.

Antenna RPE within the mesh was found to be uncritical.

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

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Mesh to PMP CS, same area, adjacent frequency

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

Simulation method

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

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 –114dBm/MHz measured at the victim receiver input.

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

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

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Mesh to PMP TS, same area, adjacent frequency

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

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

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 –114dBm/MHz measured at the victim receiver input.
For adjacent channel operation (no guard channel), the probability of exceeding the target interference level is around 12%. As with the CS case, this is too high for uncoordinated operation, although it indicates that with careful deployment adjacent channel operation may sometimes be possible.

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

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

Annex D - Work of Other Bodies

ETSI WP-TM4

ETSI Working Party TM4 is developing a Technical Report for publication titled "Rules for Co-existence of P-P and P-MP systems using different access methods in the same frequency band".. This report covers the co-existence of Point to Multi-point FWA systems with other FWA systems and with Point to Point systems deployed in the same frequency band and in the same (or near) geographical area. It examines the interference scenarios and methodologies for evaluating interference, identifies critical parameters required for standards and looks at mitigation methods.

Certain key assumptions are made regarding the deployment of P-MP systems reflecting the expectation that a number of operators with frequency block assignments deploying a range of equipments utilising different multiple access methods and duplexing methods are possible. It is recognised that as a result of facilitating co-existence between the operators, some deployment constraints may result.

Interference Classes
Based upon typical Fixed Service frequency plans a set of interference classes are identified. These are summarised below:

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

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

Deployment Scenario Assumptions
In order to evaluate the degree of co-existence between P-MP 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.

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

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

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

The methodology and the interference parameters summarised above enable evaluation of the co-existence (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).

Resultant Considerations
In carrying out this evaluation a number of considerations have come to light associated with the interference classes identified above. These are summarised below:

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Class A1 and A2:

- Site sharing improves co-existence possibilities.
- Site sharing helps to reduce the guard band requirements (possibly zero)
- Near site sharing helps also.
- With no site sharing, at least one channel equivalent guard band required between adjacent operator assignments.
- Similar EIRP’s at the Central Station reduces interference.

Class A3:

- Site sharing not possible, therefore minimum seperation required.
- Separation distance can be minimised with a guard band.

Class A4:

- Exacerbated by a large number of terminal stations.
- Guard band required.

Additionally it is noted that use of RTPC, equal channelisation schemes and similar receiver performance reduces the guard band requirements. Defined uplink and downlink frequency sub-band planning reduces the number of interference scenarios for FDD P-MP systems.

Classes B1 and B2:

- Site sharing not possible, therefore minimum distance and angular decoupling required.
- Distance and angular separation can be minimized with a guard band.

Classes B3 and B4:

- Site sharing not possible.
- Geometrical decoupling impossible to achieve due to the spread of TS over the P-MP deployment area.
- High frequency separation required, usually more than one channel equivalent guard band.

Worked Examples

Finally the report provides a number of worked examples for P-MP systems in lower frequency bands and in the 26GHz band. These examples include FDD systems employing TDMA and FDMA methods and the lower frequency example examines the impact of utilising “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 co-operation between operators to the need for two equivalent channel guard bands where non-identical systems are deployed and poor co-operation exists between operators.

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Industry Canada

Deployment of facilities which generate a psfd greater than psfd A (-114 dBW/m^2 averaged over any 1 MHz), but less than or equal to -94 dBW/m^2 averaged over any 1 MHz (psfd B) at their own service area boundary are recommended to use the following coordination process:

The operator should notify the respective licensee(s) of its intention to deploy the facility(ies) along with the appropriate information necessary to conduct an interference analysis.

The recipient of the notification should respond within 30 calendar days to indicate any objection to the deployment. Objection may be based on harmful interference to existing systems[5] only.

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

If an objection is raised, then the respective licensee(s) must work in collaboration to develop a suitable agreement between the licensee(s) before the deployment of facilities. It is expected that the time frame to develop such an agreement should not exceed 30 calendar days.

Proposed facilities should be deployed within 120 calendar days of the conclusion of coordination, otherwise, coordination should be reinitiated.

Deployment of facilities which generate a psfd greater than - 94 dBW/m^2 averaged over any 1 MHz) (psfd B) at their own service area boundary is subject to successful co-ordination between the affected licensees.

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

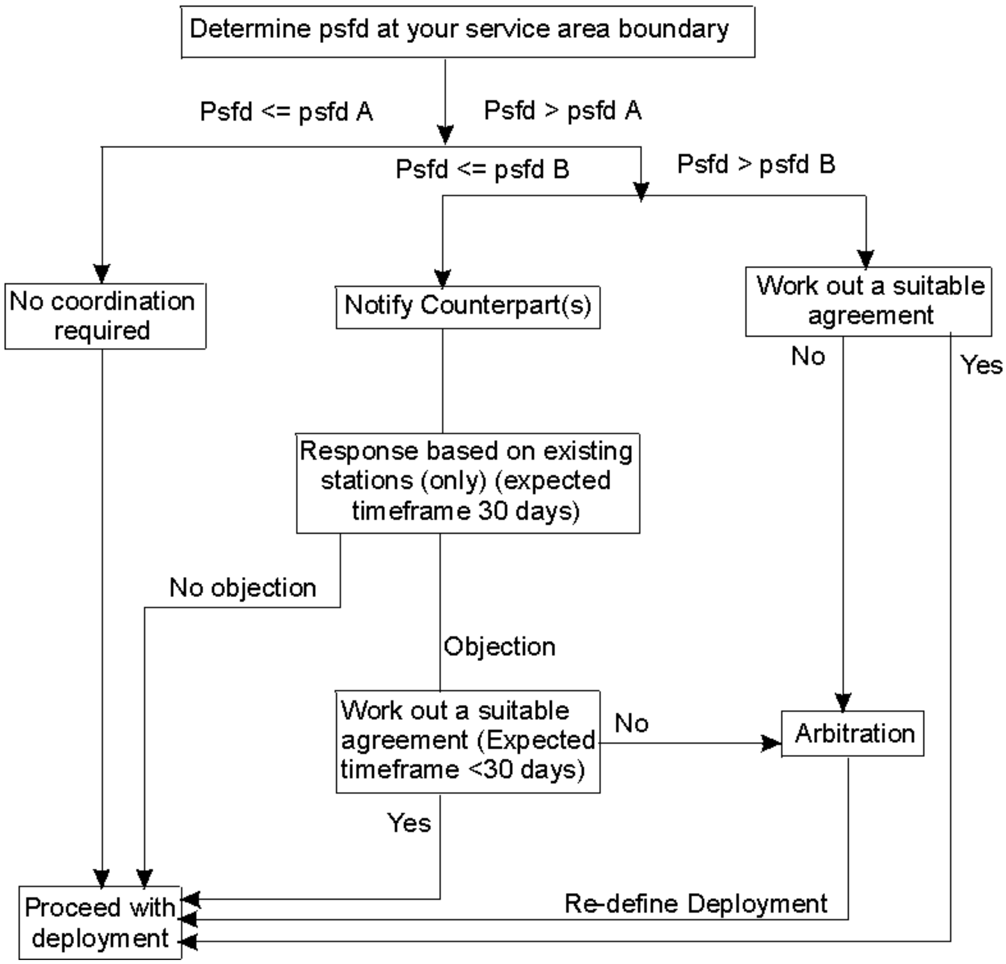
The table below summarizes the psfd levels for systems operating in the 20-30 GHz and 30-40 GHz bands.

Table - Maximum psfd Limits

Frequency Band	PSFD A (dBW/MHz-m^2)	PSFD B (dBW/MHz-m^2)
20-30 GHz	-114	-94
30-40 GHz	-125 (PTP)	-105

[5]Existing systems include systems that are operational prior to receipt of the notification, or systems that have previously been co-ordinated successfully.

Coordination process for adjacent area co-channel BWA Systems

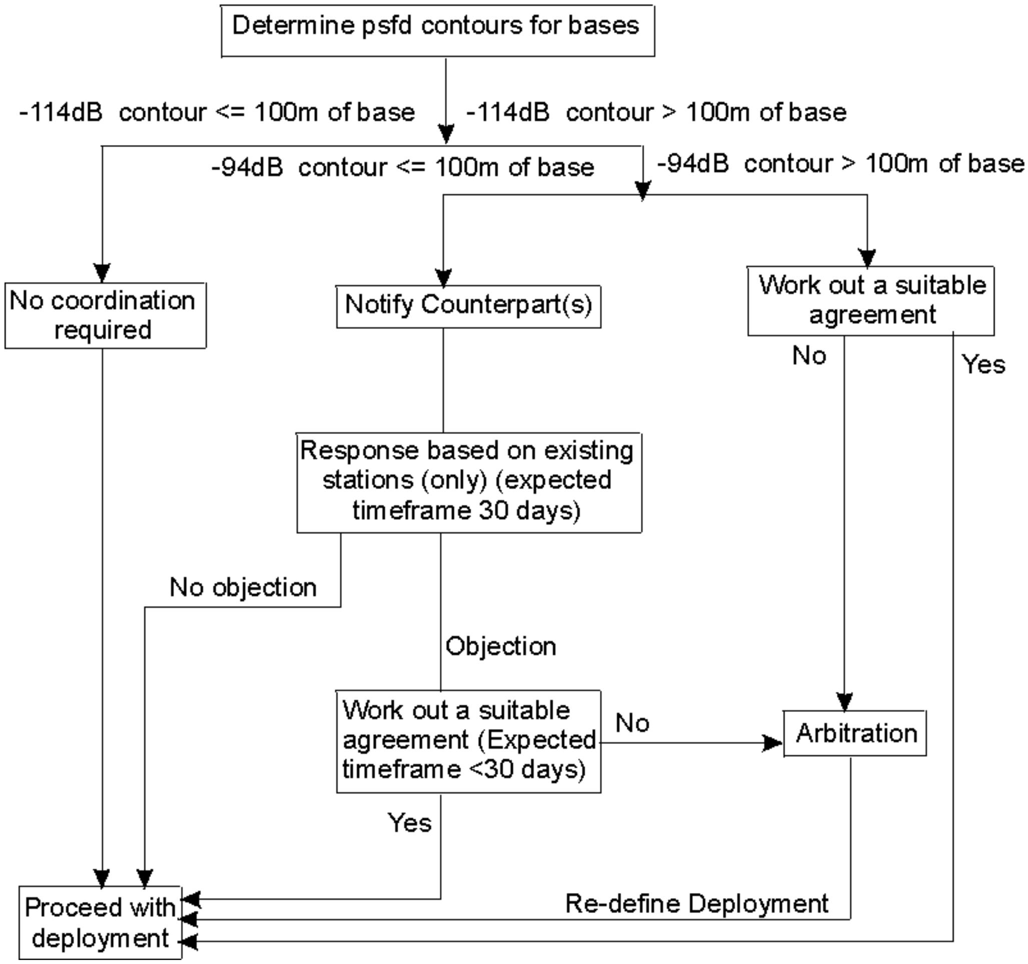


All results of analysis on psfd, or agreements made between licensees should be retained by the licensees and be made available to a regulatory body upon request.

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

In the event a satisfactory agreement or a successful co-ordination between the licensees is not reached, the regulatory body should be informed.

Figure 2 - Coordination process for same area /adjacent-channel BWA Systems



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Annex E - UK Radiocommunications Agency

Introduction

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

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

Co-ordination Triggers

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

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

The boundary psfd trigger is based upon the acceptable I/N at the typical victim receiver but reflected back to the boundary based on half the calculated MCL co-ordination 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 neighbouring licensed area but the acceptibility of this situation can be assessed by examining the probability of harmful interference.

Application of the Co-ordination distance and psfd Triggers

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

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

Trigger Values

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

28GHz Band; **-102.5dBW/MHz/m²**
40GHz Band; **-98.5dBW/MHz/m²**

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

For PMP Hub (Base Station)
28GHz Band; **27.5km**
40GHz Band; 18km

For Subscriber Stations
28GHz Band; **16km**
40GHz Band; 10km

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

Worst Case Interferer Calculations

Base Station to Base Station

Basic Link Budget equation: $\mathbf{P_{rec} = EIRP_{tx} - FSPL - L_{atmos} + G_{rec}}$

Where:

P_{rec} is the interference power at the receiver input

FSPL is the free space path loss =20 log ($4\pi R_{min}$/_)

L_{atmos} is the atmospheric loss ($0.16R_{min}$dB at 42GHz or $0.12R_{min}$ dB at 42GHz)

G_{rec} is the receiver antenna gain in the direction of the interferer

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R_{min} is the minimum seperation distance.

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

R_{min} = 36km for 40.5GHz, **therefore co-ordination distance = 18km.**
R_{min} = 55km for 27.5GHz, **therefore co-ordination distance = 27.5km.**

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

Power Flux Density: $\mathbf{pfd = P_{rec} - A_e}$

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

Therefore Boundary pfd: For 27.5GHz = -102.5dBW/MHz/m^2
For 40.5GHz = -98.5dBW/MHz/m^2

Subscriber Station Interference

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

Maximum Path Attenuation (FSPL + Atmospheric Loss + Rain Fade) = 153dB.

Therefore Maximum Cell Size: R_{max} = 2.6km for 40.5GHz
R_{max} = 4.1km for 27.5GHz

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

Therefore worst case distance: For 40.5GHz = 20.6km
For 27.5GHz = 31.6km

Max EIRP = 11.5dBW/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 given in Annex 1.

Interfering Power: $\mathbf{P_{rec} = EIRP_{tx} - FSPL - L_{atmos} + G_{rec}}$

Therefore the interfering power at the victim Base Station=

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

These two figures are both marginally below the Interference limit detailed in Annex 1.

Allowing for the effective EIRP after rain fading, co-ordination distances can be calculated.

Co-ordination Distance: 13km at 27.5GHz
8 km at 40.5GHz

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

Assuming a maximum EIRP from the subscriber station and a 10° off-boresight angle towards the boundary, then by reference to the antenna pattern referred in Annex 1, the maximum EIRP towards the boundary could be –5.5dBW/MHz.

Therefore **Co-ordination Distance: 16km at 27.5GHz**
10km at 40.5GHz

Parameter Values used for Trigger Derivation and Simulations

For the purposes of the calculating appropriate co-ordination zones, pfd trigger levels and Monte Carlo testing, the following system, deployment and propagation parameter values were assumed:

Assumed parameters for interference analysis:

Nominal channel bandwidth:	28 MHz
Base station EIRP:	15 dBW = 0.5 dBW/MHz
Base station antenna gain:	15 dBi
Base station antenna radiation pattern:	EN 301 215 class CS2
Base Station antenna downtilt	9 degrees
Subscriber station EIRP:	26 dBW = 11.5 dBW / MHz
Subscriber station ATPC assumed.	RX input level maintained at 5dB above the threshold for BER=10^{-6}.
Subscriber station antenna gain	32 dBi (PMP); 26i dB (mesh)
Subscriber station antenna 3dB beam width	4° (PMP); 9° (mesh)
Subscriber station antenna radiation pattern:	EN 301 215 class TS1
Subscriber station receiver threshold (10^{-6} BER)	-111 dBW (QPSK)
	= -125.5 dBW / MHz

Nominal operating level (threshold +5dB)	-106 dBW
Receiver noise figure	8 dB (42 GHz)
	7 dB (28 GHz)
Interference limit (kTBF – 10 dB)	-146 dBW / MHz (42 GHz)
	-147 dBW /MHz (28 GHz)
Atmospheric Attenuation	0.16 dB/km at 42GHz
	0.12 dB/km at 28GHz
Rain attenuation	7.2dB/km at 42GHz
	4.6dB/km at 28GHz

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