# Co-ordination between Broadband Fixed Wireless Access systems in the 28 and 42 GHz frequency bands

Final Report

ÆGIS spectrum engineering



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# 1. INTRODUCTION

This report describes investigations made into the intra-service co-ordination requirements for broadband fixed wireless access (BFWA) services in the 27.5 – 29.5 GHz (“28 GHz”) and 40.5 – 43.5 GHz (“42 GHz”) bands. Two distinct co-ordination scenarios are addressed, namely:

- Co-existence between two or more BFWA systems operating in the same radio spectrum and in adjacent geographic areas (“Scenario 1”).
- Co-existence between two or more BFWA systems operating in the same geographic area and in adjacent radio spectrum (“Scenario 2”)

The investigations have shown that co-existence is feasible in both scenarios providing measures are taken to minimise the risk of interference close to geographic boundaries and near frequency band edges. The principal measures that are proposed are:

**Scenario 1:**

- The application of a limit on the power flux density (PFD) that individual BFWA transmitters may generate at the licensed service area boundary.
- A requirement to co-ordinate all transmitter stations where the specified PFD limit at the licensed service area boundary is exceeded. Determination of the PFD level at the service area boundary should take account of attenuation due to terrain and other obstructions.
- Co-ordination shall not be required beyond a certain distance from the service area boundary, this distance being a function of the transmit EIRP and whether the interferer is a point to multipoint base station or a subscriber station (this distinction reflects the typically greater height and antenna beam width of PMP base stations).
- Operators in adjacent service areas should avoid co-polar, co-channel operation within 5 km of their service area boundary.
- Inter-operator boundaries should be defined as far as possible to minimise the requirement for co-ordination, by avoiding major population centres and taking advantage of prominent terrain features, to provide isolation.

**Scenario 2:**

- For services operating in adjacent spectrum within the same geographical area and utilising significantly different RF channel bandwidths, it is recommended that each operator should maintain a guard band equal to a single channel spacing. Transmissions should only take place within this guard band by mutual agreement between the operators concerned.

- For services operating in adjacent spectrum within the same geographical area and utilising identical RF channel bandwidths, it is recommended that each operator should maintain a guard band equal to half the channel spacing.
- It is recommended that the CW interference requirement in the relevant ETSI standards should be amended to +30 dBc at carrier offsets of $\pm$ 2.5 times the channel spacing or greater.

These measures are intended to enable any combination of network architecture, transmit / receive duplex scheme or multiple access scheme to be deployed. Full details of the proposed co-ordination criteria are presented in Section 6 of this report. The preceding sections provide background information on the types of BFWA system likely to be deployed in the UK, the approaches being taken to licensing and co-ordination elsewhere in the world, and describe the analytical work carried out to develop the proposed co-ordination criteria.

Standardisation and regulatory bodies both within and outside Europe are also addressing these issues and trying to understand how BFWA and MWS might best be deployed to encourage successful implementation. Within CEPT SE19 work has taken place to examine general guidelines for FWA which has culminated in a draft ERC Report “Fixed Wireless Access (FWA) Spectrum Engineering & Frequency Management Guidelines (Qualitative)” [reference SE19 Doc. 100r4]. This provides guidance material that might be usefully considered along with the conclusions of this report.

# 2. BFWA CHARACTERISTICS

A number of different approaches to BFWA might be taken by prospective UK operators. Characteristics that may vary between networks include network topology, degree of traffic asymmetry between network and subscriber, and the choice of duplexing scheme. One of the objectives of this study is to establish generic co-ordination criteria that can be applied to all BFWA services in a specific frequency band, regardless of service type, technology or network architecture. Development of such generic criteria requires consideration of all the likely deployment options, so that the reasonable protection requirements of each can be addressed whilst minimising the regulatory burden on individual operators. The following sections address the various system parameters that have been considered and describe how these might influence inter-system co-ordination requirements.

## 2.1 Network Topology

### 2.1.1 Point to Multipoint (PMP) networks

Most currently operational wireless fixed access networks, whether broad or narrow band, use PMP topology, with elevated base stations serving a number of subscribers in a given cell or sector (Figure 2.1). In an idealised scenario, cells are planned on a regular repeat pattern with typical cell radii up to 3 – 5 km depending upon the frequency band. At frequencies above 20 GHz, the pattern is constrained by the need for all subscriber stations to have a clear line of sight to a base station. The base station must be located on a relatively high point within the cell to maximise coverage. In many cases, it is difficult to achieve line of sight access to more than 50 – 60% of potential subscribers from a single base station. Multiple overlapping base stations are likely to be required to ensure an adequate level of coverage in most areas. This also provides additional diversity to counter external interference where it arises, by aligning the subscriber with an alternative base station.

To provide connections to a reasonable number of subscribers, the base station antenna requires a wide antenna azimuth beam width. Depending upon the local demand for service, each cell may be split into “sectors”, each employing a specific set of radio frequencies. A typical cell may have anything between 2 and 8 sectors, although in practice 3 and 6 are most commonly used (unsectored cells may also be used, typically in rural areas). Sectorisation reduces the likelihood of interference between cells because of the limited azimuth beam width of the base station antenna. The correspondingly higher antenna gain also improves the link budget, enabling greater distances to be served. Base station azimuth beam widths typically lie in the range 60° to 120°.

To maximise the traffic carrying capacity of the available spectrum, frequencies are re-used in cells that are sufficiently distant not to suffer undue interference. In figure 2.1 for example, a four cell repeat pattern is assumed, which means that cells A and

B will use the same radio frequencies for their base and subscriber stations. The likelihood of interference between these two cells can be minimised by using base station antennas with a relatively narrow elevation beam width, or down-tilting the axis of the base station antenna. In some cases interference may still arise, requiring the ad-hoc use of an alternative re-use pattern on the part of the operator. Operators may reserve one or more RF channels to substitute the regular channel in a particular sector where interference arises.

Because of their elevated nature and the relatively wide antenna beam widths involved, interference between PMP base stations is likely to be the most common interference scenario encountered between adjacent or co-located BFWA networks. Interference to or from subscriber stations is less likely to arise, since more directional antennas are involved (typically 4° to 9° beam width compared with 60° or more for base stations). The use of ATPC on the return path also reduces the risk of interference from subscriber stations (see section 2.8). However, since there are likely to be far more subscribers than base stations, subscriber station interference may make a significant statistical contribution to the overall performance of a network.

In this study interference to and from both base and subscriber stations in PMP networks, and between PMP and mesh networks, has been considered.

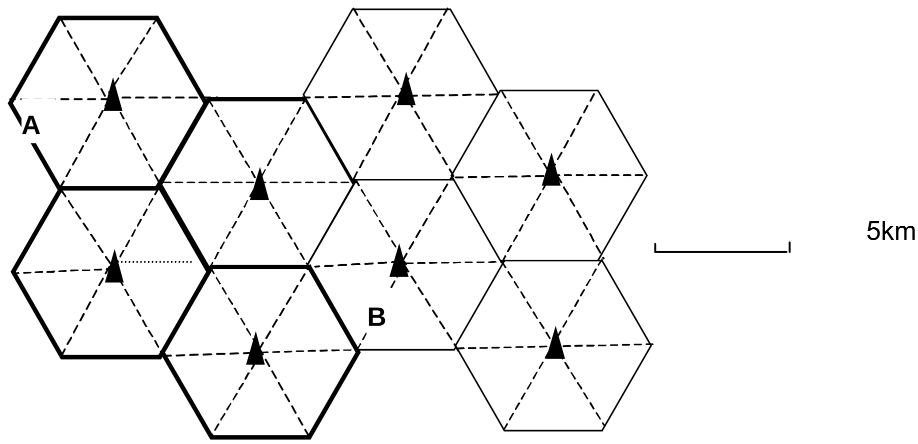



**Figure 2.1 Typical idealised PMP topology, based on a 4 x 6 cellular re-use pattern**

### 2.1.2 Mesh Networks

Unlike PMP networks, mesh networks do not employ base stations. Instead, each subscriber station functions as a repeater station or “node” enabling traffic to be routed on an ad-hoc basis around an interconnected network of point to point links, or to be originated from or delivered to its subscribers. Transmissions are not broadcast to many subscriber stations over a wide area (as with PMP base stations) but are conveyed between nodes. According to proponents of mesh networks this architecture results in substantial improvements in spectrum efficiency and network capacity.

Directional antennas and automatic transmitter power control (ATPC) may be used throughout mesh networks. Line of sight visibility is required only between specific nodes and traffic can be routed around terrain or other obstacles that would block the signal from a conventional PMP base station. Such obstructions may indeed be advantageous since they reduce the levels of unwanted interference between nodes or between adjacent networks. According to one UK proponent of mesh networks, Radiant Networks PLC, nodes would comprise typically up to four directional antennas with 3 dB beam widths of between 3° and 9°. These would provide point to point connectivity between nodes up to 3 km apart.

In this study, we have considered interference between mesh networks and between mesh and PMP networks.

## 2.2 Duplexing Scheme

Duplexing is the process by which uplink traffic (i.e. traffic flowing from the subscriber to the network) and downlink traffic (i.e. traffic flowing from the network to the subscriber) is separated. There are two principal duplexing schemes in wireless networks, namely Frequency Division Duplex (FDD) and Time Division Duplex (TDD). Figures 2.2 and 2.3 illustrate the techniques.

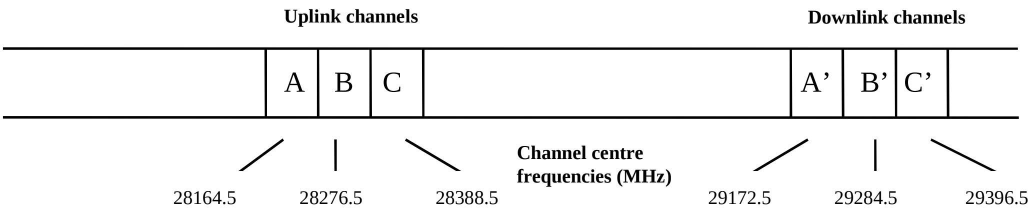



**Figure 2.2 Typical FDD arrangement (based on current 28 GHz channel plan defined in ERC Recommendation T/R 13-02)**

In figure 2.2 it can be seen that the uplink and downlink channels are separated by 1008 MHz, enabling very high degrees of rejection to be achieved between transmitters and receivers even when these are located at the same site. Co-ordination between networks is less difficult where FDD is deployed, since the most problematic interference scenario, base station to base station, is effectively eliminated.

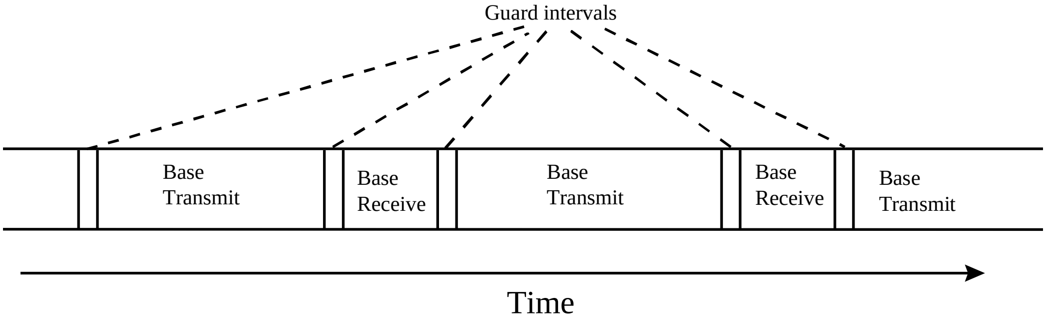



**Figure 2.3 Typical TDD arrangement (asymmetric transmission)**

With TDD, transmission and reception is carried out on the same radio frequency but separated in time (short guard intervals are required to allow for the propagation delay between transmitter and receiver). In figure 2.3, transmission is asymmetric in that the downlink (base transmit) frames are longer than the uplink frames, although the ratio between the two is constant. In practice, the duration of the uplink and downlink frames can be varied dynamically to reflect the requirements of the user. For example, in the case of a large file download the system may operate in almost continuous downlink mode, with only periodic acknowledgements returned to the network, whereas for voice telephony an equal split between up and downlink is likely to be necessary. TDD is significantly more flexible than FDD in this regard, since it is not generally practicable to re-apportion up and downlink spectrum dynamically in a PMP environment. It also seems likely that TDD will also be favoured for mesh network architectures, since the benefits of FDD are largely linked to the existence of discrete uplink and downlink channels which are no longer present in a distributed architecture.

Where multiple BFWA systems have to co-exist, the worst case co-ordination scenario is likely to involve two or more TDD systems, where the interferer may transmit at or close to the same frequency as the victim receive frequency. This assumes the two TDD systems are not synchronised, i.e. the victim receiver may be in receive mode when the interferer is transmitting. Although it is possible to synchronise TDD systems so that nearby transceivers transmit and receive at the same time, this is unlikely to be practical and would negate one of the main benefits of TDD, namely the ability to vary dynamically the transmit / receive periods.

Two scenarios are particularly problematic, namely where the interference is between two elevated, wide beam co-channel PMP base stations in adjacent areas and where the interference is between two co-located transceivers operating in adjacent frequency bands.

## 2.3 Transmission Bandwidth

The required transmission bandwidth for a BFWA system depends upon the over-the-air bit rate, modulation and multiple access scheme. The bit rate is essentially determined by the type of service being delivered. For internet access, anything between basic rate ISDN (144 kbit/s and 2 Mbit/s) may be sufficient, whereas high quality video transmission may require up to 6 Mbit/s per channel. Business users may have even greater bandwidth requirements, potentially as high as STM-1 (155 Mbit/s) for large corporate users.

The ETSI standard EN 301 213 (see annex A of this report for more details) defines minimum bit rates in Mbit/s for specific channel spacings, as follows:

| Channel spacing : | 7 MHz | 28 MHz | 112 MHz |
|---|---|---|---|
| FDMA (4-state modulation) | 4 x 2.048 | 16 x 2.048 | 64 x 2.048 |
| FDMA (16-state modulation) | 8 x 2.048 | 32 x 2.048 | 128 x 2.048 |
| TDMA (4-state modulation) | 8 | 32 | 128 |
| TDMA (16-state modulation) | 16 | 64 | 256 |

**Table 2-1: Minimum bit rates for various channel spacings (from EN 301 213)**

In practice, it is anticipated that bit rates up to STM-1 (155 Mbit/s) could be accommodated within the current ETSI transmission mask. A number of companies are considering deployment of 64-QAM modulation, which would enable STM-1 to be conveyed within a 28 MHz bandwidth. Note however that in the case of PMP networks this bit rate will represent the aggregate bit rate to or from the base station. Requirements for continuous STM-1 or higher connectivity are likely to continue to be met by point to point means.

LMDS systems in North America also deploy a variety of bit rates, depending upon the application. A typical configuration is 45 Mbit/s downstream and 2 – 10 Mbit/s upstream. In the UK, some operators may opt for a downstream bit rate of 38 Mbit/s, corresponding to the multiplex capacity for digital satellite television[1].

A particular problem arises when systems using different channel widths operate in adjacent blocks of spectrum. This is because the roll off rate of the emission mask is related to the necessary bandwidth of the emission. Hence the out of band emissions for a 112 MHz channels will be significantly greater than for 28 MHz transmissions. Therefore the guard band required at the edge of an operator's spectrum assignment to protect services in the adjacent spectrum assignment will be dependent upon that operator's chosen RF channelling arrangement. This is illustrated in figure 2.4, which shows a comparison between the transmission masks for high capacity TDMA systems with 28 MHz and 112 MHz channel spacings.

[1] Source: Broadband Wireless Association

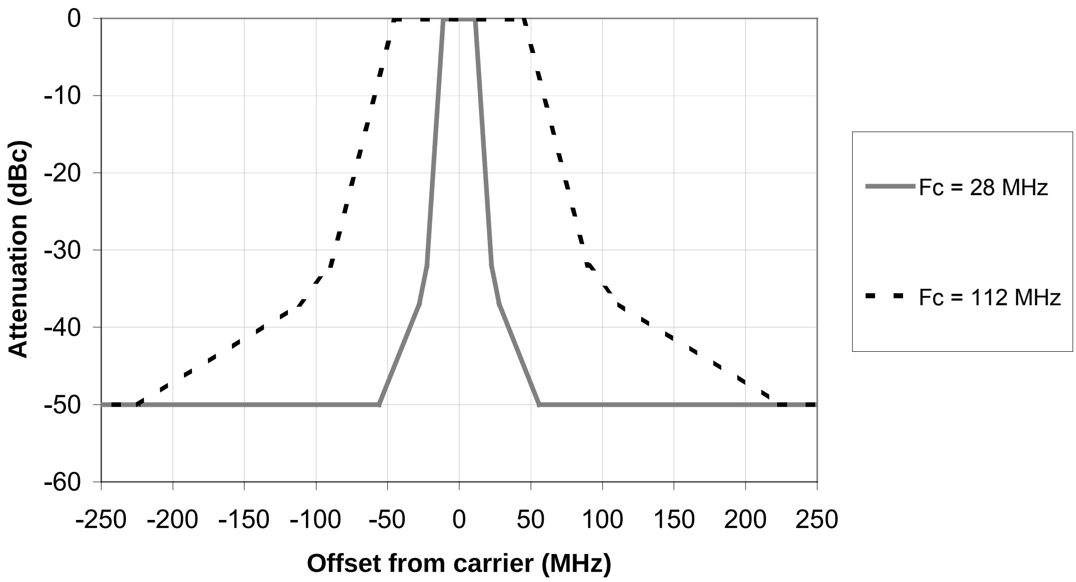



**Figure 2.4: Comparison of transmission mask roll off for 28 MHz and 112 MHz systems (based on EN 301-213, TDMA type B)**

## 2.4 Transmitter and Receiver characteristics

### 2.4.1 Introduction

In developing co-ordination criteria it is necessary to make some assumptions about the technical characteristics of the transmitters and receivers involved. So long as the reference characteristics against which the criteria were determined are specified, the criteria can then be applied to any alternative scenarios by using appropriate correction factors. For the purposes of this study, we have used the characteristics defined in draft ESTI standard EN 301 213 (see below). We have also acquired data from a number of commercial sources and from the FCC. From this information we have defined standard reference models for BFWA transmitters and receivers that can be applied to either the 28 or 42 GHz frequency bands. The following sections summarise the information gathered and the models we have defined.

### 2.4.2 EN 301 213 (draft ETSI standard)

This document is currently in draft form, however most of those currently planning to deploy BFWA systems in the UK are basing their system specifications on this standard, pending any further developments in ETSI TM4 (Transmission and Multiplexing, Fixed Radio systems). A summary of the parameters specified in EN 301 213 that are relevant to network co-existence is presented in annex A of this report.

### 2.4.3 Commercial LMDS systems (28 GHz)

The following table provides examples of current commercially available North American LMDS and LMCS equipment.

| Manufacturer | RF Bandwidth | Base tx power | Base noise fig | Base antenna gain | Subscriber tx power | Subscriber noise fig | Subscriber antenna gain |
|---|---|---|---|---|---|---|---|
| Hewlett Packard | 40 MHz | 0 dBW | 4 dB | 20 dBi (resid)<br>35 dBi (busi) | | 6 dB | 35 dBi |
| Millitech | 450-750 MHz (downstream)<br>11 to 41 MHz (upstream) | 0 dBW | 6 dB | 15 dBi | -10 dBW | 7 dB | 36 dBi |
| Wavecom | Up to 1 GHz | 0 dBW | | | -10 dBW | 5 dB | 36 dBi |
| SpectraPoint (Hughes) | 40 MHz | 0 dBW | | 14-21 dBi | -10 dBW | | 36 dBi |

**Table 2-2: Examples of commercial LMDS equipment:**

Note that depending upon the application, some manufacturers specify the full operational bandwidth (which may cover the full available band in the case of multi-channel FDMA downlinks) while others specify the individual channel bandwidth.

### 2.4.4 CEPT system examples

As part of its work on inter-service sharing, CEPT ERC project team SE 19 proposed a number of typical system examples. These have also been submitted to ITU-R for inclusion in an update of Recommendation F 758 ( Considerations in the development of criteria for sharing between the terrestrial fixed service and other services). The examples are summarised in table 2.3 below.

| Type -> | Mesh | Unidirectional MVDS | Multi-access | Interactive MVDS |
|---|---|---|---|---|
| Data rate (Mbit/s) | up to 100 | 34 | 11 | N/A |
| Modulation | QPSK | QPSK | QPSK | QPSK/16QAM |
| Channel width (MHz) | 10 – 75 | 39 | 19.5 | 8 – 36 |
| Base transmit EIRP (dBW) | N/A | 12 | 9 | 15 |
| Base antenna gain (dBi) | N/A | 15 | 15 | 15 |
| Base noise figure (dB) | N/A | N/A | 7 | 5 |
| Base receiver threshold (dBW) | N/A | N/A | -115 | -118 |
| Subscriber transmit EIRP (dBW) | 6 – 23 | N/A | 26 | 24 |
| Subscriber antenna gain (dBi) | 22 – 35 | 32 | 38 | 34 |
| Subscriber rx noise figure (dB) | 7* | 7 | 8 | 6 |

*includes allowance for min. 2 dB feeder / antenna system loss N/A: not applicable or not specified.

**Table 2-3: Examples BFWA systems considered by PT SE 19**

### 2.4.5 Proposed UK BFWA systems

Discussion with prospective suppliers of BFWA hardware for the UK market suggests that similar characteristics to those listed in section 2.4.3 will apply, although subscriber antenna gain is likely to be somewhat lower at typically 33 dBi (4° half power beam width). For mesh networks, shorter links are likely to deploy wider beam antennas, up to 9° half power beamwidth (25 dBi gain). In general, transmitter and receiver characteristics are expected to conform to EN 301 213 and antennas to EN 301 215 or MPT 1560.

### 2.4.6 FCC requirements

Emission limits for LMDS systems are defined in Federal Code of Regulations title 47 (47 CFR), chapter 1. The spectrum mask is based on the following formula:

$$A = 11 - 0.4(P - 50) \quad \text{dBc}$$

where: A is the attenuation below the mean output power level

P is the frequency offset from the carrier as a percentage of the designated emission bandwidth

The mask is shown graphically in figure 2.5 for a designated emission bandwidth of 112 MHz. Attenuation greater than 56 dB is not required.

EIRP is limited to 55 dBW total for all stations and to 42 dBW / MHz for subscriber stations. Further limits on aggregate emission levels are defined for the sub-band 29.1 - 29.25 GHz, which is shared with FSS feeder links. Otherwise there are no specific emission limits for co-ordination purposes.

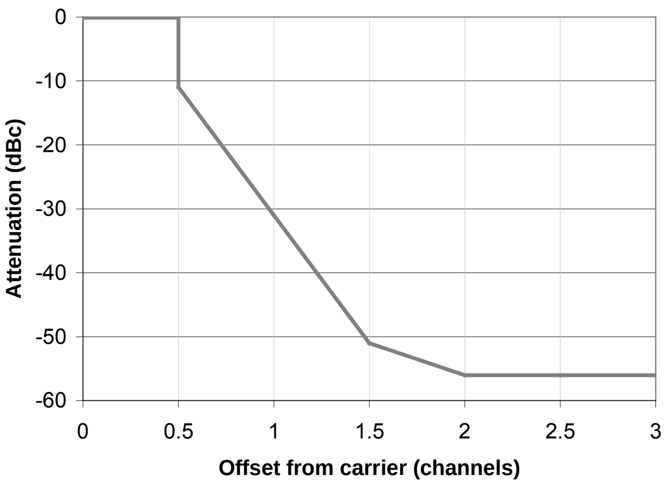



**Figure 2.5: FCC spectrum mask**

### 2.4.7 Multiple Access Techniques

There are two principal multiple access techniques likely to be deployed in a BWFA network, namely:

**FDMA** (Frequency Division Multiple Access), where individual traffic channels are carried on individual RF channels. This can be advantageous for the delivery of continuous high bandwidth data streams (10 Mbit/s or above) but on its own can be inflexible as RF channels cannot readily be split between multiple users. Transmission capacity can be maximised, at the expense of greater interference susceptibility and reduced range, by the use of high level modulation schemes such as 64 QAM. FDMA is therefore ideally suited to serving larger users with relatively constant high bandwidth requirements but within a relatively short range of the network base station. FDMA channels can sometimes be switched dynamically to TDMA (see below), at the expense of a lower overall bit rate, to cater for varying traffic profiles.

**TDMA** (Time Division Multiple Access), where individual traffic channels comprise one or more time slots making up a multi-slot “frame” which is transmitted on an individual RF channel. Each slot can be allocated to a different user, or slots can be combined to provide a single user with multiples of the basic per-slot bandwidth. TDMA is thus more flexible for bandwidth on demand applications but the need for additional digital signal processing overheads reduces the bandwidth efficiency and typically limits the modulation scheme to 16QAM or lower. TDMA is therefore best suited to applications such as Internet browsing where a large number of users require intermittent access at varying data rates. TDMA is usually deployed in conjunction with frequency division multiplexing (FDM), where several multi-slot channels are transmitted simultaneously on separate RF channels.

## 2.5 System Examples

The following examples are intended to illustrate the typical approach to operational PMP and mesh networks.

### 2.5.1 Point to Multipoint (PMP)

An experimental 42 GHz PMP system was installed in the UK in February 1998 by Hughes Network Systems and Millitech Corporation, in association with cable operator Eurobell. The trial, under the auspices of the EU funded CRABS programme, included a full range of broadcast and two-way services at over-the-air bit rates of 2 Mbit/s. Line of sight coverage over distances of up to 5 km was claimed. Subscriber stations comprised an integrated outdoor unit with a 30 cm diameter antenna and integral RF transceiver. The base station comprised a post-mounted RF transceiver with bolt-on small aperture horn antennas providing 90$^{o}$ sector coverage. QPSK modulation was used to optimise coverage range, although 16QAM modulation had been demonstrated successfully under favourable propagation conditions. Downstream and upstream channel spacings were 30 MHz and 1.8 MHz respectively. Time Division multiplexing was used on the downlink and Frequency Division multiplexing on the uplink. ATPC was deployed on the uplinks.

Base stations were sited on suitably elevated sites, although it was observed that the best base station sites in terms of line of sight coverage were not generally the tallest building in the cell area. This was primarily because of difficulties in connecting to subscribers close to the base station, whose receiving antennas would have been underneath the main beam of the base station antenna. To overcome this problem, the base station beam was down tilted by 15$^{o}$ relative to the horizontal.

The link margin was based on a minimum 18 dB carrier to noise ratio (corresponding to $10^{-8}$ BER). Allowing for rain fading, ranges of 4 – 5 km were claimed with 99.99% availability, falling to 2 – 3 km for 99.997% availability.

### 2.5.2 Mesh

One of the leading proponents of mesh networks is the UK based Radiant Networks PLC. Radiant claims that its technology can deliver up to 25 Mbit/s full duplex to residential subscribers and can be up to fifty times more spectrum efficient than PMP. The technology can be deployed in any suitable band, including the 28 or 42 GHz bands. Radiant's technology does not employ base stations; instead, each subscriber station or "node" acts as a repeater, transmitting and receiving information both for itself and for other subscriber stations. Each node can support multiple, directional, line of sight links with other nodes, providing route diversity within the mesh network and enabling routing around obstacles.

Connection to the backbone network is achieved via "trunk network connection points" (TNCPs) at bandwidths of STM-1 or higher. Each TNCP is connected to the mesh by means of several (e.g. 4 to 8) "mesh insertion points" (MIPs). The TNCPs and MIPs may be interconnected by a point to point radio link using the same frequency band as the mesh network itself. Initial coverage may be provided by deploying "seed" nodes that only receive and transmit information, no subscriber being attached. These may be linked to one another or to a MIP or TNCP. The Radiant mesh network architecture is illustrated in figure 2.6.

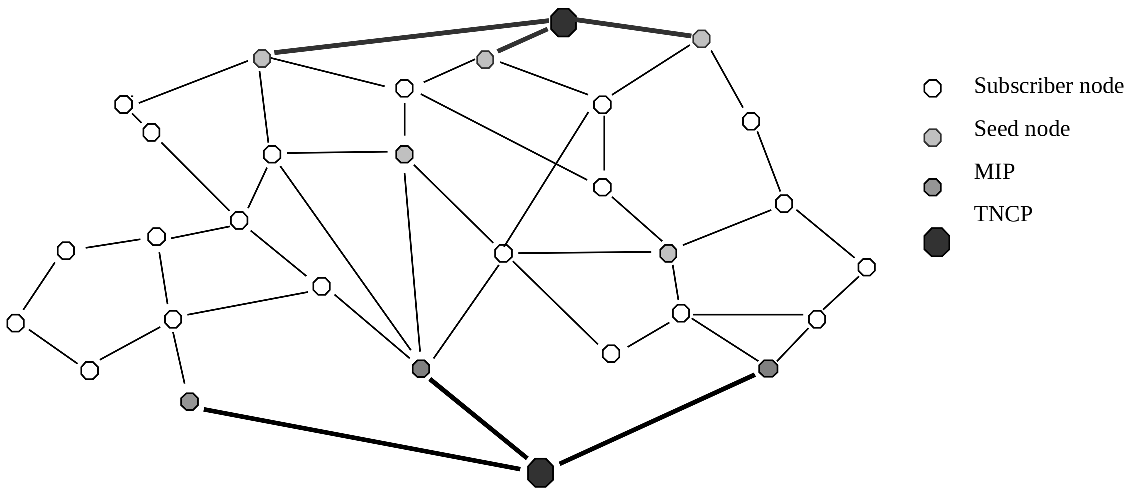



**Figure 2.6: Illustration of Radiant Networks mesh architecture**

## 2.6 Reference models used in the interference analyses

Taking account of the parameters defined in EN 301 213, the example systems proposed in CEPT PT SE 19 and of typical commercially available LMDS equipment, the following reference characteristics have been defined for the purposes of interference analysis. A relatively low gain base station sector antenna has been assumed as this will have the widest beam width and hence will have the greatest probability of generating or receiving interference.

**Assumed BFWA 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 C2 |
| Subscriber station EIRP: | 26 dBW = 11.5 dBW / MHz |
| Subscriber station antenna gain | 33 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 |
| 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) |

The above reference values do not preclude the use of higher antenna gains or EIRPs. The deployment of higher of lower EIRPs will affect the distance from the service area boundary at which co-ordination with adjacent operators is required. Graphs are presented for each frequency band defining the relationship between EIRP and co-ordination distance.

## 2.7 Propagation considerations

Propagation at frequencies above 20 GHz essentially requires a line of sight path between transmitting and receiving stations. Hence BFWA networks are designed to ensure line of sight at all times between base and subscriber stations (or between nodes in the case of mesh networks). The presence of clutter or terrain obstacles leads to rapid attenuation of the interfering signal. For example, studies have shown that at these frequencies attenuation due to a single tree is typically 30 dB[2], while building obstructions typically produce 60 dB or more.[3]

The probability of interference arising between high density BFWA networks is therefore highly dependent upon the probability of a line of interference path. This probability in turn depends on the nature of the local terrain, numbers and types of buildings, and the heights of the interferer and victim antennas relative to local clutter. Work carried out by the CRABS consortium in support of a draft new ITU-R Recommendation[4] suggested that in a typical urban environment the probability of a line of sight path at a distance of 3.5 km varied between 58 % and < 1%, depending upon the heights of the transmitter and receiver antennas.

For a line of sight path, the free space path loss is:

$$\text{FSPL (dB)} = 20 \log (4\pi R/\lambda)$$

where $R$ = path length

$\lambda$ = wavelength

Additional attenuation results from atmospheric absorption (principally due to oxygen and water vapour) and rain. At the frequencies used for BFWA, the only significant temporal variation in path loss is due to rain attenuation, which itself depends upon the instantaneous rainfall rate. The relationship between rainfall rate and specific attenuation (i.e. the additional path loss per km due to rain attenuation) is shown in figure 2.7[5].

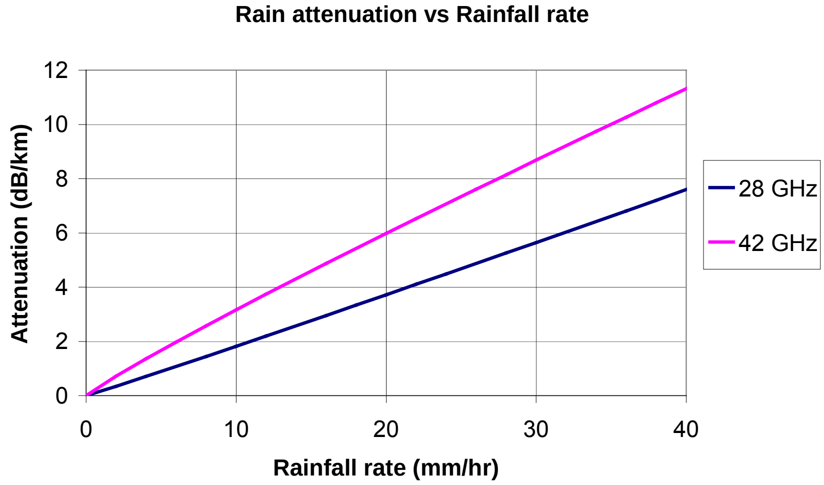



**Figure 2.7 Comparison of rain attenuation at 28 GHz and 42 GHz**

2 I. J. Dilworth & B. L'Ebraly, "Propagation effects due to foliage and building scatter at millimetre wave frequencies, Antennas & Propagation 4-7, pp 51 – 53, April 1995

3 E. J. Violetter et al, "Mm wave propagation at street level in an urban environment", IEEE Trans. On Geoscience & Remote Sensing, pp 368-380, May 1988

4 ITU-R document 3/BL/30-E, "Draft New Recommendation on Propagation data and prediction methods required for the design of terrestrial broadband millimetric radio access systems operating in a frequency range of about 20 – 50 GHz", June 1999

5 Based on ITU-R Recommendation 530, 99.99% availability

Links are designed typically to operate reliably for a pre-determined minimum percentage of time over the course of a year. This percentage is referred to as the “availability” of the link. In the case of BFWA networks, it is anticipated that most networks will be designed to provide a minimum availability of 99.99%, corresponding to a cumulative outage time of 52 minutes per year. In the UK, depending upon the region, the rainfall rate exceeded for 0.01% of time lies between 25 and 35 mm / hr. Thus individual links must have a sufficient fade margin to overcome rain attenuation corresponding to these rainfall rates.

For our interference analyses, we have assumed the following propagation characteristics:

- Line of sight path unless otherwise stated
- Atmospheric attenuation of 0.16 dB / km at 42 GHz and 0.12 dB / km at 28 GHz (principally absorption due to oxygen and water vapour)[6]
- Rain attenuation of 7.2 dB / km at 42 GHz, 4.6 dB / km at 28 GHz (this parameter is used to determine the maximum cell size or link length which in turn determines the maximum subscriber transmit power after ATPC is applied). The figures correspond to a rain rate of 25 mm / hour. At higher rain rates the maximum cell size is reduced and interference levels will be lower (because the subscriber stations will be subject to greater ATPC reduction).

## 2.8 Automatic Transmitter Power Control (ATPC)

ATPC is a technique which enables the receive power in a radio link to be maintained at a nominal constant level despite changes in the propagation environment. When the link experiences rain attenuation, the transmitter EIRP is increased to compensate, up to a maximum level corresponding to the assigned rain fade margin for the link. In addition to ATPC, subscriber station EIRP is also subject to a fixed attenuation to maintain a constant signal level at the base station receiver regardless of the separation distance. The nominal receive signal level at the base station is set typically up to 5 dB above the receiver threshold (usually defined in terms of a $10^{-6}$ bit error rate). This provides a margin for imperfect power control loops or imprecise power measurements and ensures substantially error free operation for most of the time.

As a general rule downstream transmissions in PMP BFWA networks do not deploy ATPC. This is because of the shared nature of the downstream signal, which is effectively “broadcast” to all users within a cell (although only individual users may be able to access data at any given time). Downstream ATPC is used in some mobile applications (e.g. GSM) to reduce inter-cell interference, and its future deployment in BFWA systems could reduce the probability of interference between adjacent networks’ base stations, particularly where the networks are operating

[6] Based on Annex 2, figure 5 of ITU-R Recommendation P 676-3

unsynchronised TDD. However on the basis of current practice it has been assumed that PMP base stations transmit at full power continuously. In mesh networks, ATPC is likely to be used throughout, to facilitate frequency re-use and maximise network capacity.

The effect of ATPC on inter-network co-existence is to reduce the mean level of cumulative interference between networks. The extent of this reduction depends on the degree of correlation between fading of the wanted and interfering signals.

## 2.9 Correlation of rain fading

The effect of a distant interferer depends upon the degree to which fading of the interfering signal is correlated with fading of the wanted signal. Fading occurs when the signal passes through an area in which rain is falling, commonly referred to as a "rain cell". Statistical studies[7] have shown that typical rain cell sizes are of the order of 4 – 5 $km^2$. Where the interfering signal arrives at an angle close to the boresight of the victim antenna, it experiences substantially the same degree of rain fading as the wanted signal. This condition, referred to as correlated rain fading, reduces the effective interference into the victim receiver by an amount equal to the rain fade margin applied to the wanted link.

Conversely, interference received at angles away from the victim antenna boresight may not pass through the rain cell and may therefore be unfaded. This situation is known as uncorrelated rain fading and is assumed to apply at angles > ± 10° off boresight. Uncorrelated rain fading has a further effect when considering interference from subscriber stations that deploy ATPC. Interference received via the side or back lobes of subscriber stations may be enhanced when the interfering EIRP is increased to counter rain fades.

For analysis purposes, we have simulated the effects of correlated and uncorrelated rain fade margins on the wanted and unwanted signal levels by reducing the subscriber station antenna gain within ± 10° of boresight by a factor equivalent to the rain fade margin at the edge of a typical cell. (Note that subscriber stations at the cell edge operate with the lowest link margin and are therefore the most susceptible to interference).

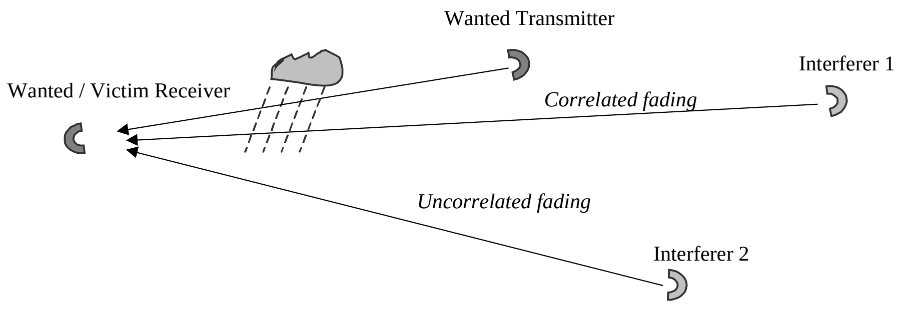



**Figure 2.8: Correlated and uncorrelated rain fading**

[7] H. Sandler, "Propagation model for coexistence modelling", IEEE 802.16 doc 16cc-99/15

# 3. CO-EXISTENCE BETWEEN TWO OR MORE BFWA SYSTEMS OPERATING IN THE SAME RADIO SPECTRUM AND IN ADJACENT GEOGRAPHIC AREAS ("SCENARIO 1").

## 3.1 General Approach

This section develops appropriate co-ordination criteria based on projected worst case and statistical interference scenarios. The approach taken is to establish appropriate PFD levels at specific distances from a single interfering transmitter that will ensure interference at a suitably located co-channel receiver in an adjacent service area does not exceed the limit (kTBF – 10 dB) defined in section 2.6. Statistical analyses are then carried out using a Monte Carlo method to assess the effect of multiple interferers.

Co-ordination between BFWA services in adjacent geographic areas primarily involves providing sufficient electrical separation between co-channel transmitters and receivers. Separation between transmitters and receivers operating on adjacent channels may also be required close to service area boundaries, particularly if systems are operating with different channel spacings and emission bandwidths.

The minimum separation distance between interfering transmitters and victim receivers to avoid co-channel interference depends upon a number of factors. These include:

- antenna gain
- antenna beam width
- antenna pointing angle
- antenna height
- terrain features
- clutter due to buildings, foliage and other obstructions

In many cases the path between interferer and victim or the off-axis discrimination of their antennas may be sufficient to allow operation at very close proximity. The geography and population distribution within the UK is such that it is possible to define regions in such a way that areas where significant co-ordination is required are away from population centres, or are shielded by terrain features. It is therefore unlikely that there will be any part of the UK where BFWA services may not be provided assuming certain co-ordination criteria are met.

Where the location of a transmitter at a particular location would result in a significant risk of interference to the adjacent service area, we propose that co-ordination should be carried out with the adjacent area operator to ensure that interference will be maintained below a mutually acceptable threshold. In this study, we have attempted to define such a threshold as a power flux density (PFD) limit at the operators' licensed service area boundary. It is assumed that this boundary will be based on clearly defined entities such as county borders or terrain features and that service will be constrained to within this boundary as a condition of the licence.

In determining this PFD threshold we have assumed equipment parameters based on those specified in section 2.6. The threshold has been determined assuming a single interferer and a free space, directly aligned path between interferer and victim – essentially a “minimum coupling loss” approach. The threshold has then been tested using Monte Carlo statistical analysis to check its validity in a typical multiple interferer environment.

## 3.2 Interference from Point to Multipoint (PMP) networks

### 3.2.1 Base station to base station interference

#### *3.2.1.1 Introduction*

Figure 3.1 illustrates the geometry of the PMP base station to base station interference scenario. This is expected to be the most significant interference scenario by virtue of the wide antenna beam widths and relatively high elevations involved.

Whilst terrain and clutter obstructions make line of sight visibility of subscriber stations beyond the service area boundary increasingly unlikely, there is a strong probability that an adjacent base station could be visible, particularly if both the interferer and victim are elevated significantly above the local terrain and clutter.

The following sections cover:

- Derivation of PFD limits at the service area boundary, using the reference transmitter and receiver characteristics defined in section 2.6. Note that for each band the lowest frequency has been chosen (i.e. 40.5 and 27.5 GHz), as these have the lowest path losses and will therefore require the greatest co-ordination distances.
- Derivation of an appropriate maximum co-ordination distance, based on the PFD limits and assuming a single interferer and victim with line of sight visibility between the two. This co-ordination distance is the distance from the service area boundary within which transmitter stations should be co-ordinated with adjacent area operators, if the transmitter EIRP and the transmission path in the direction of the boundary are such as to cause the boundary PFD limit to be exceeded. To reduce the need for co-ordination in mature networks with smaller cell sizes (and hence correspondingly lower base station EIRPs) the co-ordination distance is defined in terms of the transmitter EIRP.

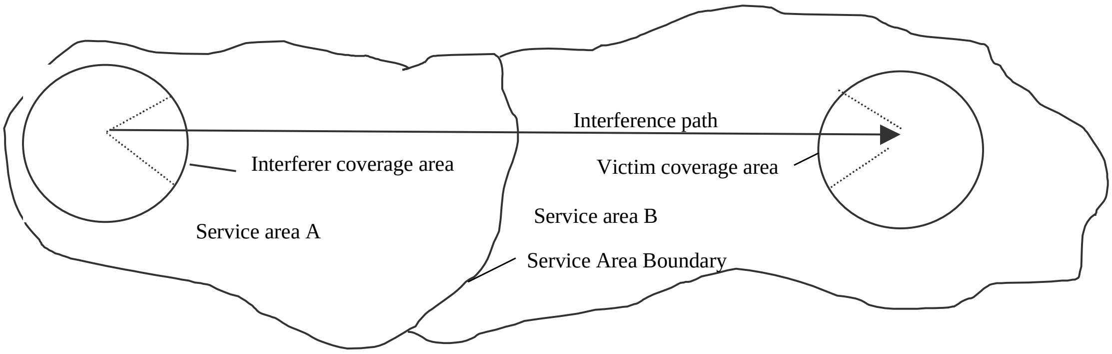



**Figure 3.1 Base station to base station interference scenario**

### *3.2.1.2 Worst case single interferer scenario: 40.5 GHz calculations*

Assuming a 15 dBi victim antenna gain and 0.5 dBW/MHz interferer EIRP, the minimum separation between the two ($R_{min}$) can be derived from the link budget equation, i.e.,

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

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

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

$L_{atmos}$ is the atmospheric loss ($0.16R_{min}$ dB)

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

Figure 3.2 shows the received interference power as a function of the separation distance from the interfering transmitter.

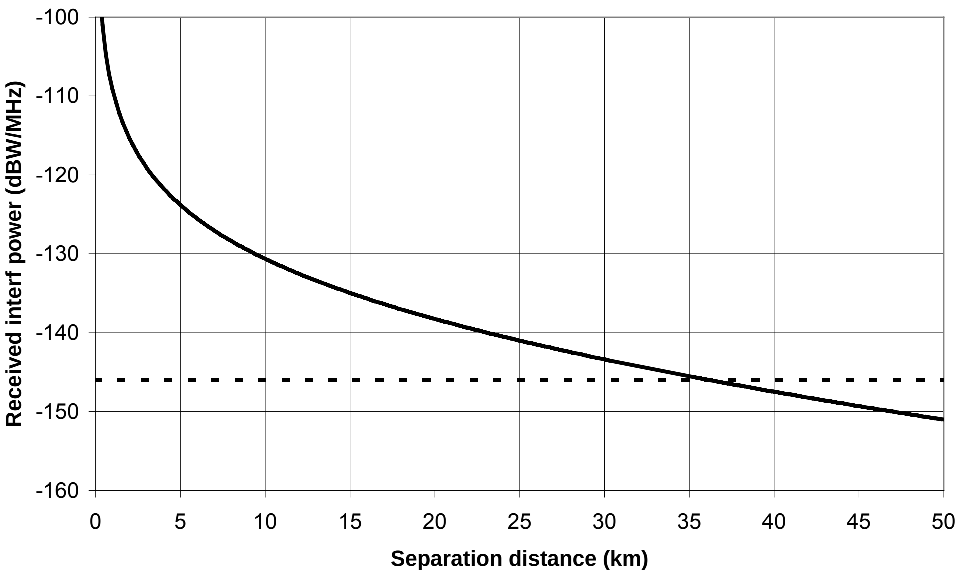



**Figure 3.2: Received interference power vs. separation distance for the base station to base station interference scenario (40.5 GHz, line of sight)**

To meet the –146 dBW / MHz interference criterion defined in section 2.6, a separation between directly aligned base stations under clear air conditions of **36 km** is required.

The PFD at the victim receiver can be determined using the formula

$$\mathbf{PFD = P_{rec} - A_e,}$$

where $A_e = G_{rec} + 10 \log (\lambda^2/4\pi)$ (the receiving antenna effective aperture)

$= - 38.6 \text{ dB m}^2$

Thus the PFD corresponding to the interference limit of –146 dBW / MHz with a receiver antenna gain of 15 dBi is -146 - (-38.6)

$= - 107.4 \text{ dBW/MHz/m}^2$

The PFD generated by our reference base station as a function of distance from the base station transmitter is shown in Figure 3.3.

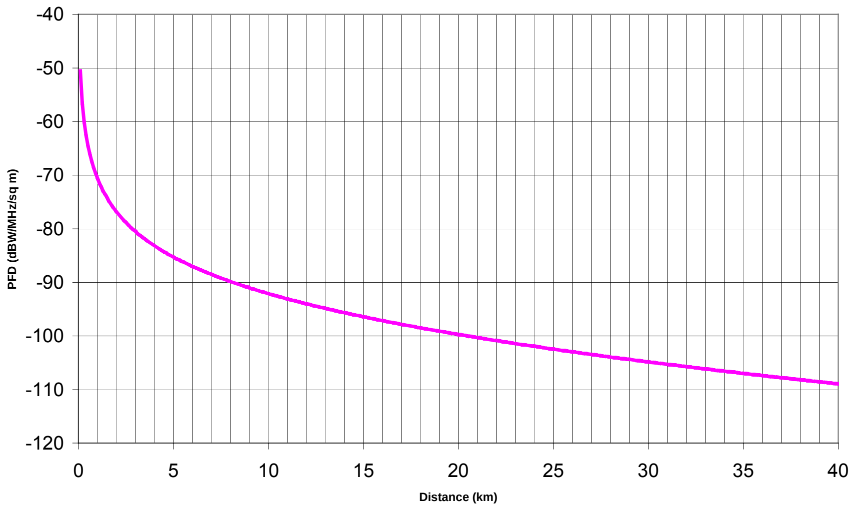



**Figure 3.3: PFD vs. distance from interfering transmitter (0.5 dBW/MHz interferer EIRP)**

If the required separation distance is apportioned equally between the two regions, this will require each operator to ensure any base station *directly aligned* with an adjacent operator's service area boundary is located at least 18 km away from the adjacent service area boundary. This does not mean that base stations cannot be located closer to the boundary. Rather, the PFD at the boundary should be no greater than that which would be produced via an unobstructed path by a directly aligned transmitter radiating 0.5 dBW / MHz EIRP at a distance of 18 km from the adjacent service area boundary. At closer distances to the boundary, additional protection in the form of reduced antenna gain in the direction of the boundary or shielding from terrain or other obstacles will be required. The extent of additional protection required is indicated in Figure 3.4. From Figure 3.3, the PFD at the service area boundary, produced by a base station 18 km away and radiating 0.5 dBW / MHz EIRP, is **$-98.5 \text{ dBW/MHz/m}^2$**.

**It is therefore recommended that co-ordination between operators using co-channel 40 GHz assignments in adjacent geographic areas should take place for any transmitter that generates a PFD of – 98.5 dBW/MHz/m$^2$ or greater at the service area boundary. The distance from the service area boundary that will be subject to co-ordination, as a function of transmitter EIRP, is indicated in Figure 3.5.**

Where it is necessary to deploy base stations close to the boundary, measures should be taken to reduce the PFD to less than –98.5 dBW/MHz/m$^2$, by means of one of the following:

- Alignment of the antenna away from the service area boundary
- Positioning the base station to take advantage of terrain screening between the base station and the service area boundary
- Downtilting the base station antenna
- Use of reduced EIRP

Where none of these options are feasible, co-ordination should be undertaken with the adjacent area operator(s).

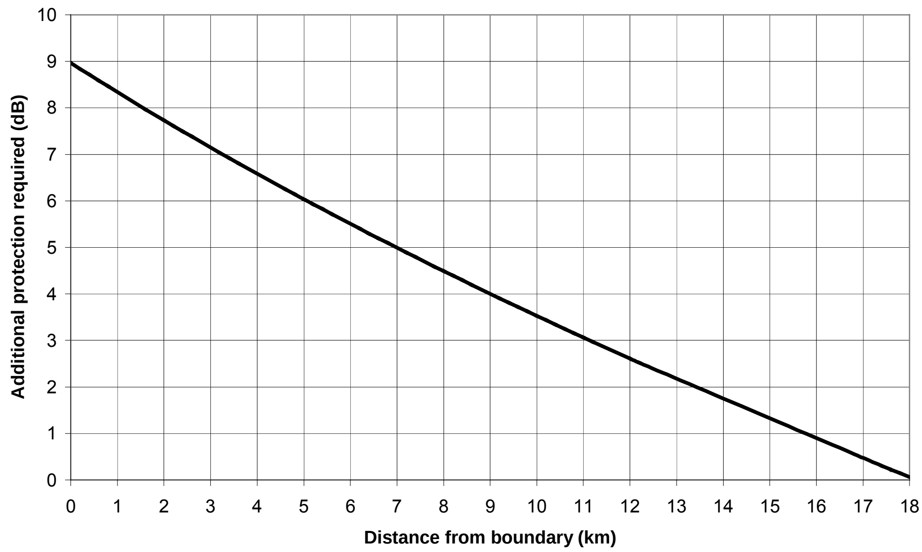



**Figure 3.4: Additional shielding or off-axis discrimination required for base station as a function of distance from service area boundary (42 GHz band)**

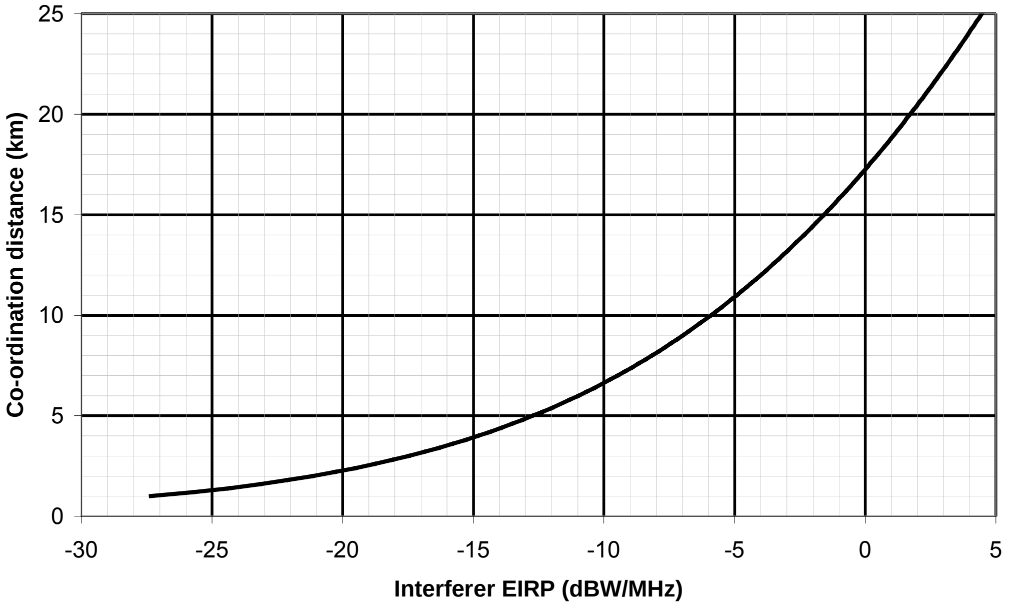



**Figure 3.5: Co-ordination distance (from service area boundary) as a function of interferer EIRP) at 40.5GHz**

These measures will also have the effect of ensuring interference into the base station receiver remains at an acceptable level. To be fully protected from interference under line of sight conditions, a receiving base station with a 15 dBi antenna directly aligned with the service area boundary will need to be set back by 18 km from the service area boundary.

The interference from a base station meeting the boundary PFD criterion into a base station located *at the boundary* but pointing its antenna directly away from the boundary will be as follows, assuming an antenna consistent with EN 310 215:

PFD = –98.5 dBW/MHz/$m^2$

$G_{rec}$ = 15 – 25 = -10 dBi

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

= 15 - 149.6 – 2.9 - 10

= -162 dBW/MHz (i.e. well below the interference threshold)

To ensure that the interference received from a single base station interferer is at or below the kTBF – 10 dB threshold, the antenna gain in the direction of the interferer should be less than 6 dBi.

#### 3.2.1.3 *Worst case single interferer scenario: 27.5 GHz calculations*

Assuming a 15 dBi victim antenna gain and 0.5 dBW/MHz interferer EIRP, the minimum separation between the two ($R_{min}$) can be derived from the link budget equation, i.e.,

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

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

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

$L_{atmos}$ is the atmospheric loss (0.12$R_{min}$ dB)

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

Figure 3.6 shows the received interference power as a function of the separation distance from the interfering transmitter.

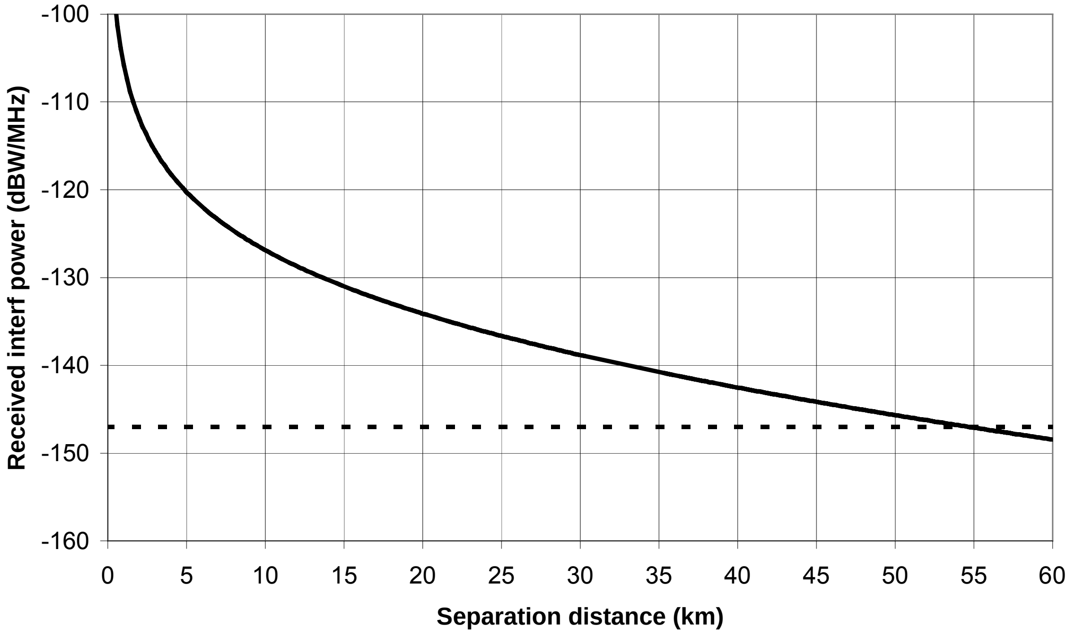



**Figure 3.6: Received interference power vs. separation distance for the base station to base station interference scenario (27.5 GHz, line of sight)**

To meet the –147 dBW / MHz interference criterion defined in section 2.6, a separation between directly aligned base stations under clear air conditions of **55 km** is required.

The PFD at the victim receiver can be determined using the formula

**PFD = $P_{rec}$ - $A_e$,**

where $A_e$ = $G_{rec}$ + 10 log ($\lambda^2/4\pi$) (the receiving antenna effective aperture)

= - 30.6 dB $m^2$

Thus the PFD corresponding to the interference limit of –147 dBW / MHz with a receiver antenna gain of 15 dBi is -147 - (-30.6) dBW/MHz/$m^2$

= - 116.4 dBW/MHz/$m^2$

The PFD generated by our reference base station as a function of distance from the base station transmitter is shown in Figure 3.7:

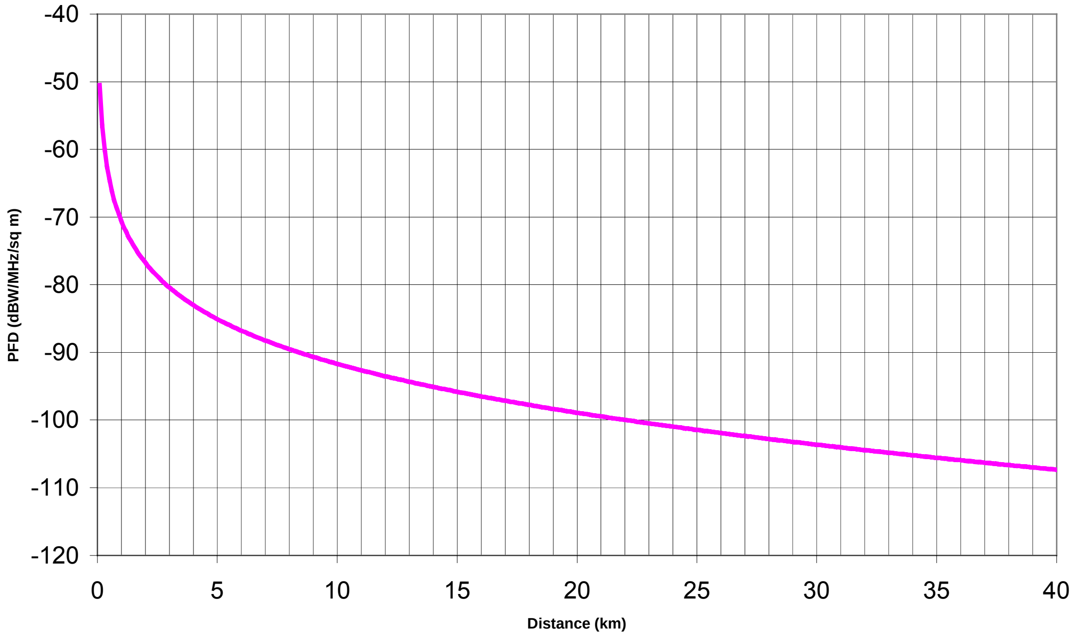



**Figure 3.7: PFD vs. distance from interfering transmitter (0.5 dBW/MHz interferer EIRP, 27.5 GHz)**

If the required separation distance is apportioned equally between the two regions, this will require each operator to ensure any base station *directly aligned* with an adjacent operator's service area boundary is located at least 27.5 km away from the adjacent service area boundary. This does not mean that base stations cannot be located closer to the boundary. Rather, the PFD at the boundary should be no greater than that which would be produced via an unobstructed path by a directly aligned transmitter radiating 0.5 dBW / MHz EIRP at a distance of 27.5 km from the adjacent service area boundary. At closer distances to the boundary, additional protection in the form of reduced antenna gain in the direction of the boundary or shielding from terrain or other obstacles will be required. The extent of additional protection required is indicated in . From Figure 3.7, the PFD at the service area boundary, produced by a base station 27.5 km away and radiating 0.5 dBW / MHz EIRP, is **-102.5 dBW/MHz/m$^2$**.

**It is therefore recommended that, for the 28 GHz band, co-ordination between adjacent operators should take place for any transmitter that generates a PFD of – 102.5 dBW/MHz/m$^2$ or greater at the service area boundary. The distance from the service area boundary that will be subject to co-ordination, as a function of transmitter EIRP, is indicated in Figure 3.8.**

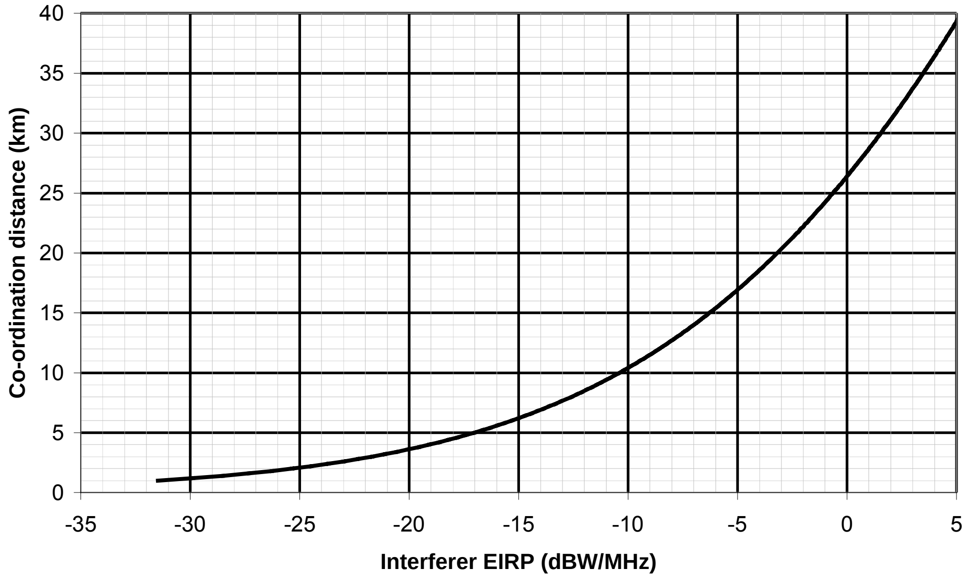



**Figure 3.8: Co-ordination distance from service area boundary as a function of transmitter EIRP) at 27.5 GHz**

Where it is necessary to deploy base stations close to the boundary, measures should be taken to reduce the PFD at the boundary to less than –102.5 dBW/MHz/m$^2$, by means of one of the following:

- Alignment of the antenna away from the service area boundary
- Positioning the base station to take advantage of terrain screening between the base station and the service area boundary
- Downtilting the base station antenna
- Use of reduced EIRP

Where none of these options are feasible, co-ordination should be undertaken with the adjacent area operator(s).

To be fully protected from interference under line of sight conditions, a receiving base station with a 15 dBi antenna directly aligned with the service area boundary would need to be set back by 27.5 km. Where receiving stations are located within 27.5 km of the boundary, care should be taken to avoid direct alignment over a line of sight path with neighbouring regions. The degree of extra protection required, either by way of off-axis antenna discrimination or terrain / building shielding, is shown in Figure 3.9 as a function of distance from the service area boundary.

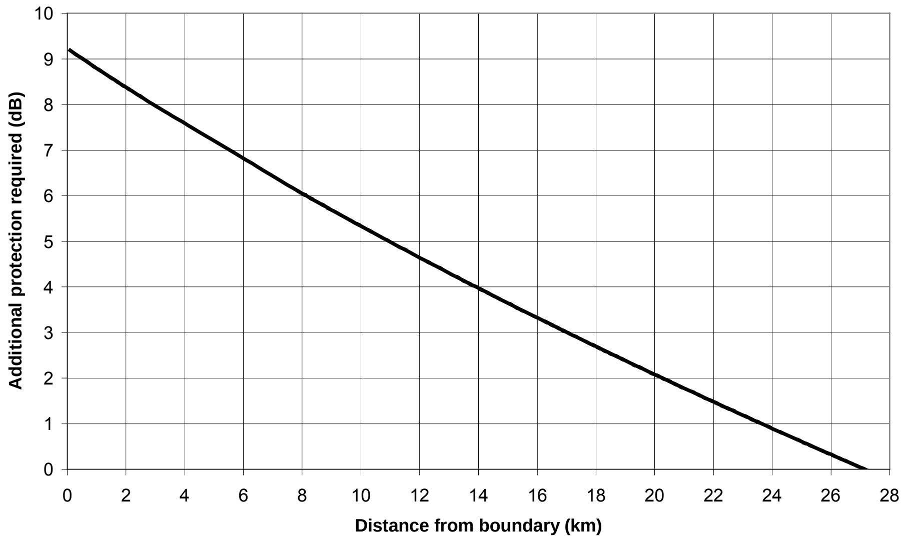



**Figure 3.9: Additional shielding or off-axis discrimination required for base station as a function of distance from service area boundary (28 GHz band)**

*3.2.1.4 Multiple interferer statistical analysis at 27.5 GHz*

The geographic density of the interfering base stations can be determined by considering a typical cellular re-use pattern of 4. The minimum separation distance (D) between co-channel base stations is given by:

**$D = \sqrt{(3 \times 4)}R = 3.46R$ [8],**

where: R is the cell radius.

The average geographic density of interferers may thus be calculated, assuming a uniform distribution of cells and a nominal cell radius of 3 km:

Density of base stations per $km^2 = 1/(3.46 \times 3)^2$

$= 0.009$ per $km^2$

For modelling purposes we have assumed the scenario illustrated in Figure 3.10, with a base station density of 0.009 per $km^2$. It is assumed that interferers may be visible up to a distance of 60 km from the base station, and that those within 27.5 km of the service area boundary have their EIRPs reduced accordingly to maintain the boundary PFD limit. The victim base station antenna is located at the service area boundary and assumed that it subject to the minimum 9 dB shielding indicated in Figure 3.9. This is considered to be the worst case location in terms of the probability of line of sight interferer visibility. At higher interferer densities, the cumulative interference is likely to fall because of the corresponding reduction in EIRPs (see section 3.3)

[8] W.C.Y. Lee, “Mobile Cellular Telecommunications Systems, McGraw-Hill, 1989

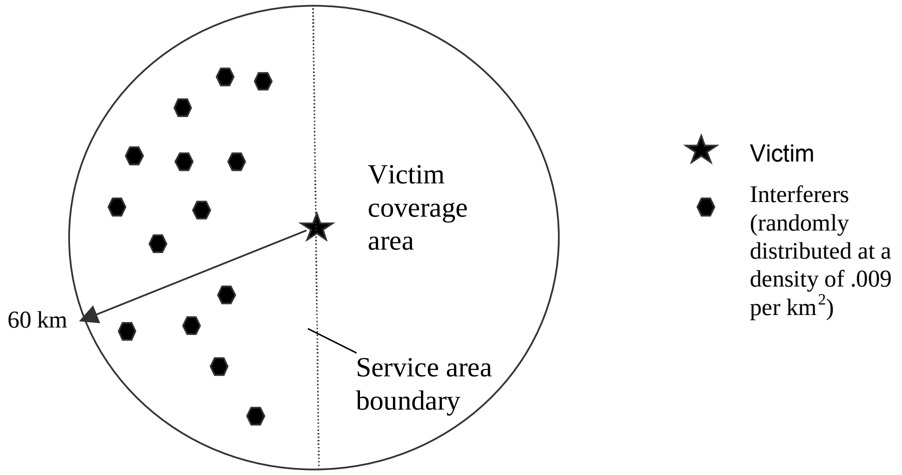



**Figure 3.10: Base station to base station interference scenario for statistical analysis**

Figure 3.11 shows the CDF for 1,000 trials based on the above geometry, assuming 90° (azimuth) by 16° (elevation) base station sector antennas conforming to EN 301-215 class CS1. Results are presented for three scenarios, with 10%, 20% and 40% of the interferers visible to the base station. If horizontally aligned base station antennas are assumed (i.e. no downtilt), there is a high probability that the interference limit will be exceeded (this is in fact not surprising, since the 55 km separation distance derived in section 3.2.1.3 was determined from a minimum coupling loss analysis of a single interferer and victim). However, when account is taken of the base station antenna downtilt that is likely to be deployed in practice to facilitate intra-network frequency re-use, cumulative interference is reduced to more acceptable levels, as shown in Figure 3.12.

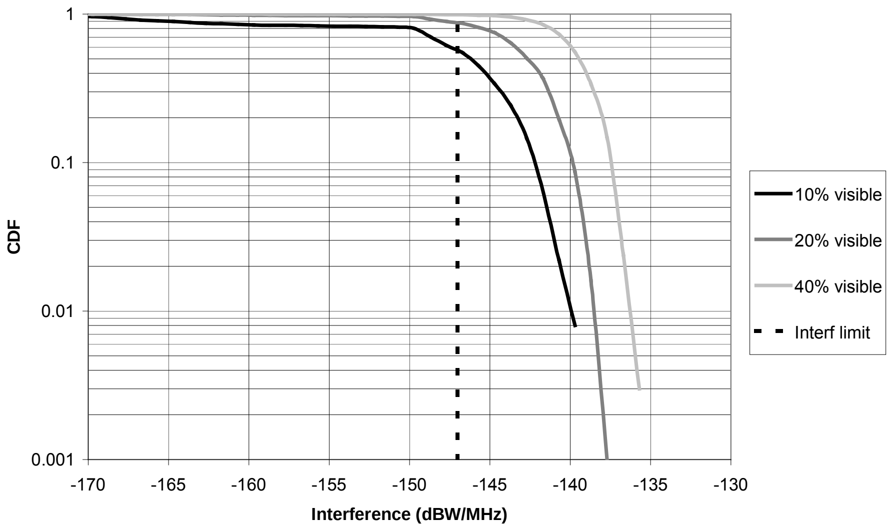



**Figure 3.11: Interference CDF for base station to base station scenario (no base station antenna down tilt)**

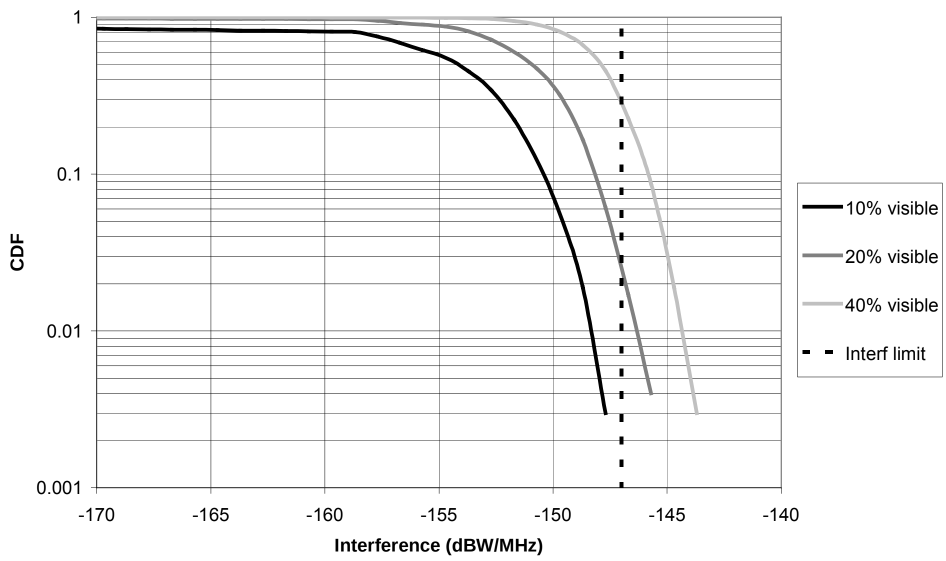


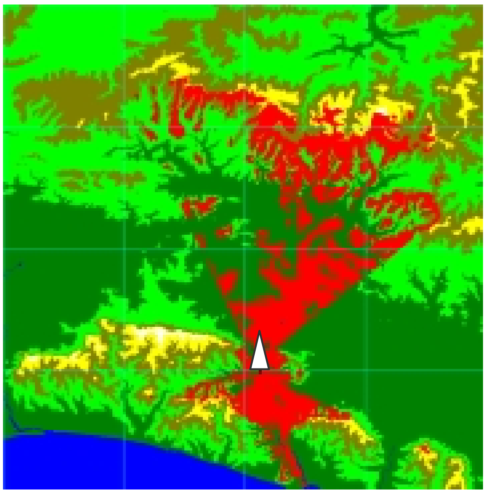

**Figure 3.12: Interference CDF for base station to base station scenario (9° base station antenna down tilt)**

It can be seen from Figure 3.12 that interference only becomes significant when 20% or more of the potential interfering base stations have a line of sight path to the victim (the 10% curve lies completely below the interference limit). Even with 40% of potential interferers visible, the interference limit at 99% of locations is exceeded by only 3 dB. This is still 7 dB below the assumed victim receiver noise floor and in practice is unlikely to lead to any significant degradation of network performance.

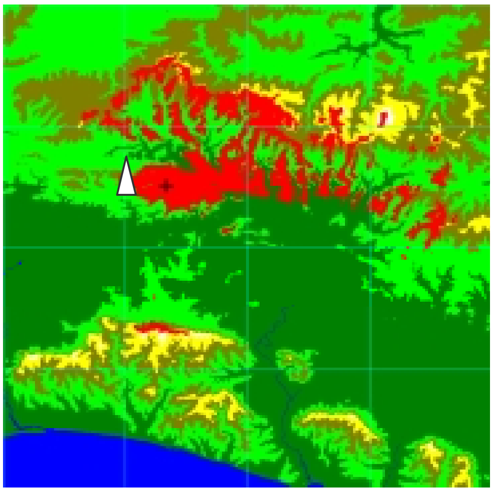
*3.2.1.5 Effect of typical terrain obstructions on the PFD contour*

To obtain an impression of the degree to which real-world terrain will limit interference from BFWA transmitters, some calculations were undertaken using the propagation model of ITU-R P.452-9 and 50m resolution terrain data for Southern England (Sussex).

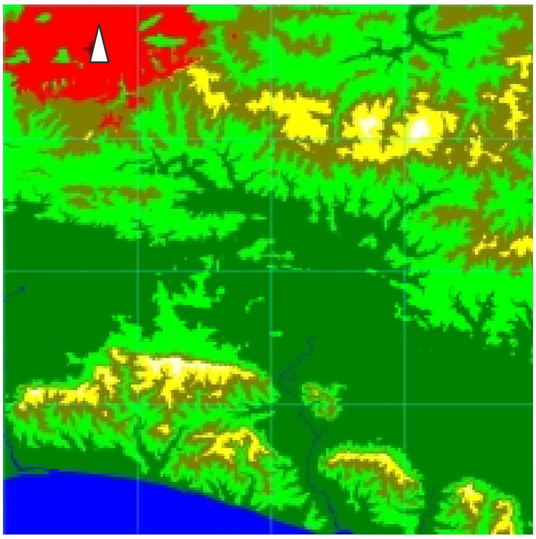
Figure 3.13 shows, for a transmitters located in Lewes, Haywards Heath and Crawley, the extent of the area over which the PFD level exceeds the limit defined in the previous section. The map shows the –102.5 dBW/MHz/m$^2$ contour (in red), assuming an operating frequency of 28 GHz and a transmitter EIRP of 0.5 dBW / MHz. For clarity an omnidirectional antenna has been assumed.



a) Lewes



b) Haywards Heath



c) Crawley



**Figure 3.13: ASSET analysis of -102.5 dBW/MHz m$^2$ PFD contours at three typical base station sites (0.5 dBW/MHz transmitter EIRP at 28 GHz)**

In each case the map area is 40 x 40 km, and it can be seen that the contour extends to the full 27.5 km co-ordination distance only where there is a clear unobstructed line of sight path. These plots do not take account of building clutter which will further reduce the extent of interference. Nevertheless, at each site for over 75% of azimuth angles the PFD contour lies within 10 km of the transmitter and even where visibility does extend towards the radio horizon this is typically only where there is significant terrain elevation.

### 3.2.2 Base station to subscriber station interference

The worst case interference from a single base station into a subscriber station will exceed the limit by a considerable margin, because of the higher victim antenna gain. For a subscriber station located at the service area boundary and having an antenna gain of 33 dBi, the boundary PFD limits defined in section 3.2.1 produce a receiver input level of **–119 dBW / MHz**. However, the probability of direct alignment will be significantly lower than in the base station to base station scenario because of the narrower beam widths involved. Interference into subscriber stations is also less of a problem in network performance terms because:

- the link margin is usually greater, since ATPC is not deployed on the downlink and the downlink EIRP includes a fixed rain fade margin.
- the height of the subscriber station victim is likely to be significantly less than that of a base station victim.
- only a single user is affected by interference into a subscriber station, rather than an entire base station sector.
- in PMP networks with overlapping base station coverage areas, it may be possible to direct the subscriber station to an alternative base station to avoid external interference, whilst in mesh networks, subscriber / repeater stations are likely to have multiple route diversity.
- In the worst case scenario, where the interferer lies directly in the victim antenna boresight, correlated rain fading can be assumed.

A statistical analysis was carried out assuming multiple base station interferers and a PMP subscriber victim located at the edge of the victim network's service area boundary. The interferer geometry is the same as in Figure 3.1, but the victim is a subscriber station rather than a base station and is pointing directly into the interferer's service area (i.e. the antenna beam is orthogonal to the service area boundary).

As noted above, the probability of a line of sight path between a co-channel interfering base station and victim subscriber station is in practice likely to be small. The radio horizon is also reduced, from 60 km to 40 km, because of the reduced antenna height at the subscriber station. Where the interferer is aligned at an azimuth close to the victim antenna boresight, correlated fading of the interferer and wanted signals can be assumed (see section 2.9). Assuming a nominal cell size of 3 km and an operating frequency of 27.5 GHz, the rain fade margin at the cell edge will be 3 x 4.6 = 13.8 dB. This factor has been modelled by reducing the gain of the subscriber receive antenna by 13.8 dB within $\pm$ 10° of the antenna boresight.

Figure 3.14 illustrates the interference CDFs for a number of interferer visibility percentages. The simulation assumed that the base station interferer antennas were down tilted by 9° from the horizontal.

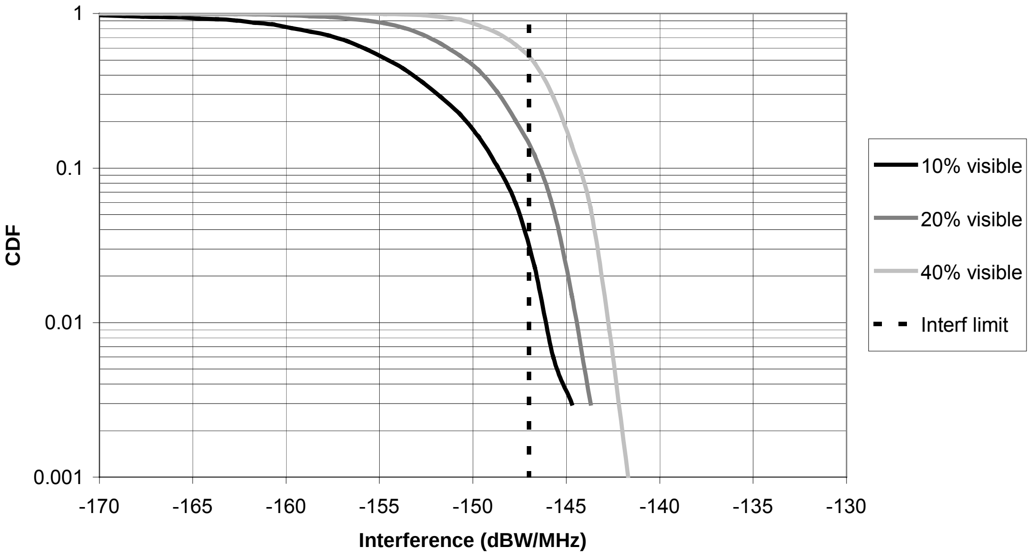



**Figure 3.14: CDF for Base-to-Subscriber interference**

It can be seen from Figure 3.14 that there is a risk of interference exceeding the (kTBF-10 dB) limit at 3% of subscriber stations when 10% of potential interfering base stations are visible, increasing to a 40% risk when 40% of the potential interferers are visible. However, the highest level of interference likely to be encountered even with 40% interferer visibility is only 5 dB above the limit. Such a margin would in practice have little if any effect on network performance. This is because very few subscriber stations are likely to operating so close to their receiver threshold level. In practice the probability of more than one or two interfering base stations being visible is slight, because of the relatively low height of the subscriber antennas. It is also likely that in mature networks a choice of base or node stations will be available, enabling susceptible subscriber stations to be oriented away from potential interference sources. Base station to subscriber station interference is therefore not considered to be a significant factor if the proposed boundary PFD limits are observed.

### 3.2.3 Subscriber station to base station interference

#### *3.2.3.1 Introduction*

In determining the interference level into a directly aligned, line of sight base station receiver from an adjacent network's subscriber station(s) it is assumed that the victim base station is set back from its network service area boundary by the minimum distance specified in section 3.2.1, i.e.:

- 18 km at 42 GHz
- 27.5 km at 28 GHz

The subscriber station is assumed to have ATPC and for the directly aligned line of sight interference scenario correlated rain fading is assumed, i.e. the interfering signal is assumed always to be attenuated by an amount corresponding to the fade margin. For the worst case interference scenario, it is assumed that the interfering subscriber station is directed towards a base station located at the network service area boundary, pointing into its own service area.

Unlike the base stations, subscriber station EIRP varies according to the distance from the home base station and whether rain fading is present. For our analysis, we have assumed that each subscriber station will have its EIRP level set to deliver a signal to the base station (or adjacent node station) 5 dB above the receiver threshold (this margin is typically applied to counter control loop and measurement uncertainties). The interference produced at the victim base station will thus depend upon the separation between the interfering subscriber station and its own base station, since the larger the separation between these two, the higher the subscriber EIRP will be.

The worst case interference arises when the subscriber station is at the maximum distance from its base and is operating at its maximum EIRP, assumed to be 11.5 dBW / MHz (from the reference model defined in section 2.6). This maximum cell size can be determined by considering the downlink power budget, assuming a base station EIRP of 0.5 dBW / MHz.

The total path loss within the cell comprises three elements, namely free space propagation loss (= 20 log (4πR/λ)), atmospheric attenuation and rain attenuation.

In the following sections, the maximum exported interference from a single subscriber station in each band is determined, by evaluating the total path loss at the lowest frequency in the band.

#### *3.2.3.2 Worst case single interferer scenario, 40.5 GHz calculations*

At 40.5 GHz, these values are as follows:

FSPL = 124.6 + 20 log R, where R is the distance in km between transmitter and receiver.

Atmospheric attenuation = 0.16 dB / km

Rain attenuation = 7.2 dB / km

Maximum path attenuation (dB) is therefore

$$P_{rec} + G_{rec} + EIRP_{base}$$

$$= 106 + 32 + 15$$

$$\mathbf{= 153\ dB}$$

The maximum cell size can thus be determined from:

$$124.6 + 20 \log R + 7.36R = 153$$

$$20 \log R + 7.36R = 28.4$$

$\therefore$ $\mathbf{R_{max} = 2.6\ km}$

The worst case interference scenario therefore occurs when the interfering subscriber station is at a distance of 20.6 km (=18 + 2.6) from the directly aligned victim base station. Assuming the subscriber station is running at the assumed maximum EIRP of 11.5 dBW / MHz, the received signal level at the victim base station at this distance is

$$= 11.5 - FSPL - L_{atmos} - L_{rain} + G_{rec}$$

$$= 11.5 - 150.8 - 3.3 - 18.7 + 15$$

$$= \mathbf{-146.3\ dBW / MHz}$$

This is marginally below the kTBF – 10 dB interference criterion and implies that the PFD limit derived for the base to base interference scenario is also applicable to the subscriber to base scenario.

Note that the PFD limit defined in section 3.2.1.2 should also be applied to transmissions from subscriber stations and mesh network nodal stations. In most cases, the lower EIRP and height will mean the PFD limit is unlikely to be exceeded even where the subscriber station is operating close to the boundary. Where the subscriber station is oriented towards the boundary (typically within $\pm$ 10° of boresight), correlation of rain fading may be assumed and the EIRP under unfaded conditions may be used for the PFD calculation. For other directions, the maximum EIRP under faded conditions must be assumed, however the antenna off-axis discrimination will reduce the EIRP in the direction of the boundary.

Assuming a maximum subscriber EIRP of 11.5 dBW / MHz and a maximum cell size of 2.6 km, the effective EIRP after allowing for rain fading (=18.7 dB) is –7.2 dBW. From Figure 3.5, this requires co-ordination at distances up to 8 km from the boundary. Assuming this same maximum boresight EIRP, uncorrelated rain fading and an off-boresight angle of 10° in the direction of the boundary, the maximum EIRP in the direction of the boundary can be determined from the difference between the boresight antenna gain and the gain at $\pm$10° offset. From EN 301 215, the maximum gain at 10° off boresight is defined as –17 dB relative to the boresight gain. Hence the maximum EIRP in this scenario is

$$11.5 - 17\ \text{dBW / MHz}$$

$$= -5.5\ \text{dBW / MHz}$$

From Figure 3.5, this EIRP implies a co-ordination distance of 10 km.

**It is therefore considered that, at 42 GHz, co-ordination of subscriber stations will not be necessary beyond 10 km from the service area boundary, assuming a maximum EIRP of 11.5 dBW / MHz. Subscriber stations within 10 km of the service area boundary should be co-ordinated on a case by case basis where the EIRP in the direction of the boundary, at the specific co-ordination distance, exceeds the EIRP value indicated in Figure 3.5.**

#### *3.2.3.3 Worst case single interferer scenario at 27.5 GHz*

The corresponding maximum cell size at 28 GHz is:

$121.2 + 20 \log R + 4.72R = 153$

$20 \log R + 4.72R = 31.8$

$\mathbf{R_{max} = 4.1\ km}$

The worst case interference scenario therefore occurs when the interfering subscriber station is at a distance of 31.6 km (=27.5 + 4.1) from the victim base station. Assuming the subscriber station is transmitting at the assumed maximum EIRP of 11.5 dBW / MHz, the received signal level at the victim base station at this distance is

$$11.5 - FSPL - L_{atmos} - L_{rain} + G_{rec}$$

$$= 11.5 - 151.2 - 3.8 - 18.9 + 15$$

$$= \mathbf{-147.4\ dBW / MHz}$$

Once again, this is marginally below the N – 10 dB criterion.

Assuming a maximum subscriber EIRP of 11.5 dBW / MHz and a maximum cell size of 4.1 km, the effective EIRP after allowing for rain fading (=18.8 dB) is –7.3 dBW. From Figure 3.8, this requires co-ordination at distances up to 13 km from the boundary. Assuming this same maximum boresight EIRP, uncorrelated rain fading and an off-boresight angle of 10° in the direction of the boundary, the maximum EIRP in the direction of the boundary can be determined from the difference between the boresight antenna gain and the gain at ±10° offset. From EN 301 215, the maximum gain at 10° off boresight is defined as –17 dB relative to the boresight gain. Hence the maximum EIRP in this scenario is

$$11.5 - 17 \text{ dBW / MHz}$$

$$= -5.5 \text{ dBW / MHz}$$

From Figure 3.8, this EIRP implies a co-ordination distance of 16 km.

**It is therefore concluded that, at 28 GHz, co-ordination of subscriber stations will not be necessary beyond 16 km from the service area boundary, assuming a maximum EIRP of 11.5 dBW / MHz. Subscriber stations located within 16 km of the service area boundary should be co-ordinated on a case by case basis when the EIRP in the direction of the boundary, at the specific co-ordination distance, exceeds the EIRP value indicated in Figure 3.8.**

*3.2.3.4 Multiple interferer statistical analysis at 27.5 GHz*

In this scenario, the interference geometry is once again as defined in Figure 3.10, with each interferer a transmitting subscriber station and the victim a PMP base station, located at the service area boundary and with 9 dB shielding in the direction of the adjacent service area (in accordance with Figure 3.9).

Although there will be far more subscriber stations than base stations, the nature of multiple access means that, for PMP systems, the cumulative interference generated by subscriber stations associated with a given base station transceiver will be no greater than the interference generated by that base station. It can be assumed therefore that the density of interfering subscribers at any instant will be no more than the density of interfering base stations. Since subscriber stations deploy ATPC, the exported interference from each cell will be time varying as different subscribers access the base station, but will average out at less than that produced by the base stations. The interference level is further reduced since correlated rain fading can be assumed when the victim lies within the interferer's antenna boresight. The interference CDFs for various interferer visibilities, taking account of these factors, is illustrated in Figure 3.15 below. An instantaneous co-channel interferer density of 0.01 per km$^2$ is assumed.

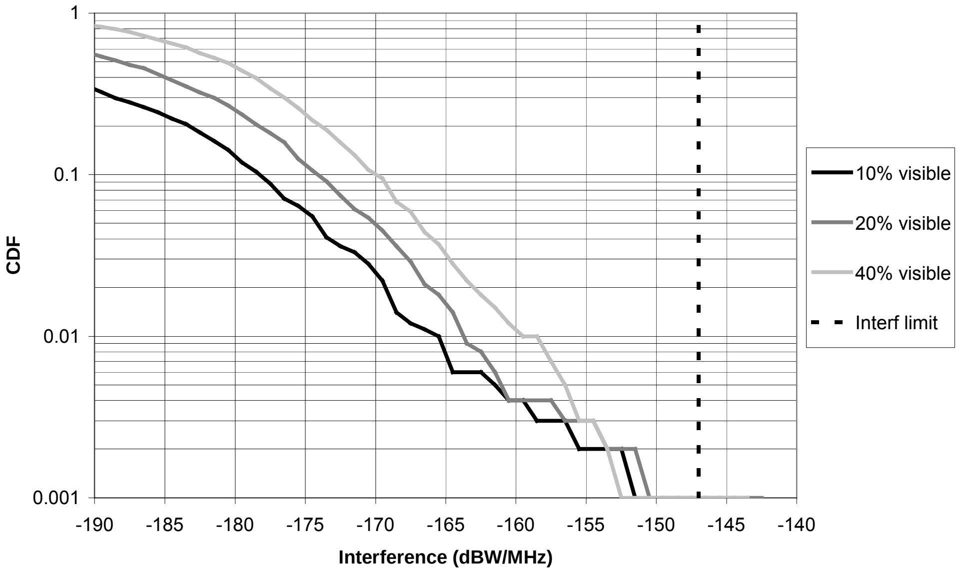



**Figure 3.15: CDFs for subscriber station to base station interference (geographically adjacent PMP networks)**

It can be seen that even with as many as 40% of the interferers visible the probability of the interference limit being exceeded at the victim receiver is less than 0.1%. Work carried out by the EU CRABS project and in the US has indicated that at distances beyond the 3 km cell size assumed here, the probability of a line of sight path between subscriber and base stations is unlikely to exceed 40%. Since interfering subscriber stations will in general be at a greater distance from the victim base station than the cell size, the proportion with a line of sight path is likely to be considerably less than 40%.

#### 3.2.4 Subscriber station to subscriber station interference

The worst case scenario in this instance involves two directly aligned subscriber stations located close to the service area boundary (although base stations close to the boundary can be oriented away from the boundary to minimise interference, this itself necessitates subscriber stations to point *towards* the boundary). The maximum interference arises when the interferer is at the maximum distance from its base station, i.e. 2.6 km at 42 GHz or 4.1 km at 28 GHz. Similarly, the victim is at its most susceptible at the cell edge, hence for the worst case (single interferer) analysis a separation distance of 5.2 and 8.2 km can be assumed for the two bands. Under this scenario, correlated rain fading can also be assumed and since rain attenuation affects both the victim link margin and the interferer EIRP rain can be assumed to affect the entire interference path. Interference into the victim subscriber station at 40.5 GHz is therefore:

$$\mathbf{P_{rec} = EIRP_{interf} - FSPL - L_{atmos} - L_{rain} + G_{rec}}$$

$$= 11.5 - 138.8 - 0.8 - 37.6 + 33$$

$$\mathbf{= -132.7\ dBW / MHz}$$

This exceeds the N – 10 dB limit by 13.3 dB. However, as previously noted the probability of this worst case scenario arising is remote and there is likely to be the option of orienting the victim subscriber station towards an alternative base or node station. The low probability of interference is clearly demonstrated by Figure 3.16, which shows the interference CDFs for various percentage visibilities. The simulation assumed an interference geometry based on Figure 3.10, with both interferer and victim defined as subscriber stations and the victim located at the service area boundary.

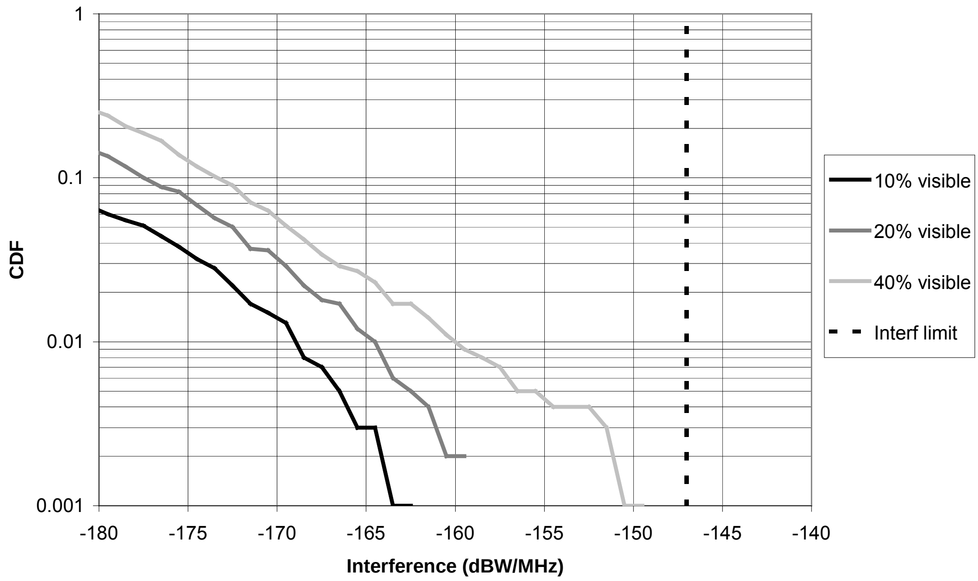



**Figure 3.16: CDFs for subscriber station to base station interference (geographically adjacent PMP networks)**

## 3.3 Interference from high density PMP networks

The above results are based on PMP networks with nominal 3 km cell radii. This reflects our assumption that service area boundaries will not pass through major population centres and that in the vicinity of the boundaries the density of base stations will be determined by coverage rather than capacity considerations. It is further assumed that, in PMP networks, the subscriber interference per cell will not exceed the interference from the base station itself. The density of active co-channel interferers at any instant is therefore relatively low (we have assumed 0.009 per $km^2$). The density of active interferers could be significantly higher if the longer term demand for BFWA services leads to the introduction of cell splitting and microcells to increase PMP network capacity. This is most likely to arise in urban areas but could affect areas close to the service area boundary if the local demand is high.

In PMP networks, reducing the cell size should lead to a corresponding reduction in transmitter EIRP levels, since these are determined by the total path loss between the base station and the most distant (cell edge) subscriber. The reduction in free space path loss to the cell edge is inversely proportional to the square of the cell size, whilst the density of interferers is proportional to the square of the cell size. However, the total path loss is reduced further due to the effect of the rain fade margin. Consequently, the cumulative interference level becomes smaller when the average cell size is reduced, despite the increased density of interferers.

## 3.4 Interference from mesh networks

In the case of mesh networks, the ad-hoc nature of network roll out is likely to mean a wide spread of link lengths, up to a maximum of 3 – 4 km, even in mature networks. Furthermore, proponents of mesh networks suggest that their capacity may be up to 50 times more than PMP networks using the same amount of spectrum. On this basis an interferer density up to 50 times that of an equivalent PMP network may be assumed. Assuming a maximum hop length of 3 km, corresponding to the 3 km cell size assumed for PMP networks, this would imply an interferer density of 0.009 x 50 = 0.45 co-channel interferers per $km^2$.

The cumulative effect of interferers at this density is directly dependent upon how many are likely to have a line of sight path to the victim receiver. Since the probability of visibility is dependent upon the elevation of the victim receiver, PMP base stations are likely to be most susceptible to interference from high density mesh networks. At distances up to the typical PMP macrocell radius of 3 km, there is likely to be a relatively high probability (50% or more) of a line of sight path to interfering subscriber stations. Conversely, assuming a four cell re-use pattern, the probability of a line of sight path at a distance corresponding to the minimum cellular re-use distance (= $\sqrt{12}$ times the cell radius) is considered to be relatively small (<20%). Assuming the victim network comprises cells of 3 km radius, the cellular re-use distance is 10.4 km.

**It is therefore recommended that, to minimise the need for individual subscriber station co-ordination, BWFA operators should avoid co-channel, co-polar operation within 5 km of their service area boundaries.**

Figure 3.17 shows the interference CDFs for interference from a high density mesh network into a PMP base station, assuming various percentages of visible interferers, a total interferer density of 0.45 per $km^2$ and a minimum 10 km separation between co-channel interferers and victim. The operational frequency assumed is 28 GHz.

Because of the narrow beam widths involved and the far lower probability of a line of sight path, interference between mesh network stations in adjacent areas, or between mesh networks and PMP subscriber stations, is unlikely to be a significant factor so long as the above co-channel separation recommendation is observed.

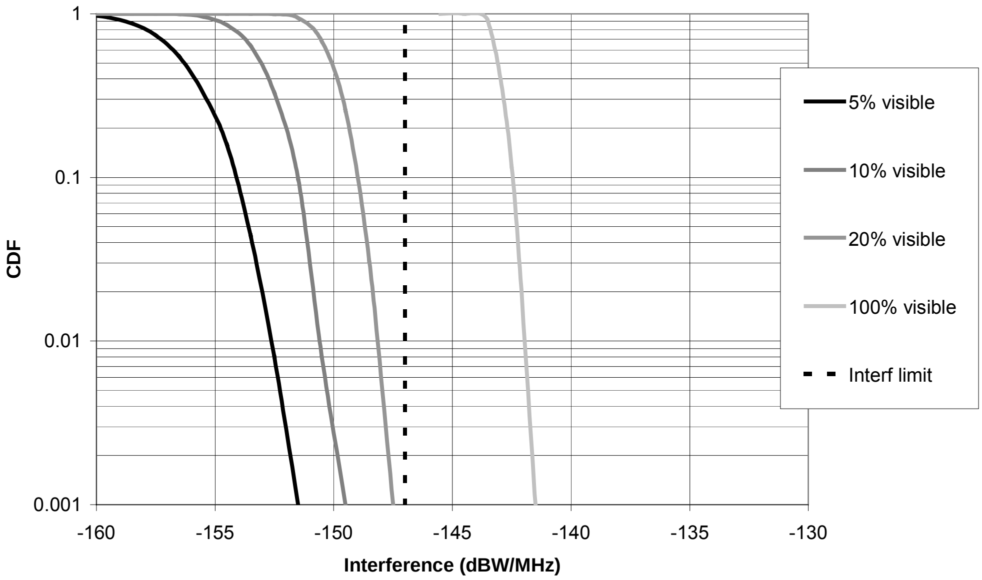



**Figure 3.17: CDF for interference from a high density mesh network into a PMP base station (no co-channel operation within 5 km of service boundary)**

It can be seen that, assuming that no more than 20% of interferers are visible, there is unlikely to be any significant risk of interference.

## 3.5 Comparison with co-ordination criteria developed elsewhere

The co-ordination criteria developed above can be compared with those proposed by other administrations around the world. Three administrations have proposed specific criteria based on PFD limits at a specified distance from the interfering transmitter. Of these, two (Germany and Switzerland) are essentially the same. The following table compares the PFD limits established in section 3.2.1 with those proposed by the German / Swiss and Canadian administrations, for frequencies in the 24 – 28 GHz range.

| | UK | Germany/Switzerland | Canada |
|---|---|---|---|
| PFD limit | -102.5 dBW/MHz/m$^2$ | -110 dBW/MHz/m$^2$ | -114 dBW/MHz/m$^2$ |
| Distance | 27.5 km | 15 km | 60 km |

It can be seen that in both the German/Swiss and the Canadian cases, the defined PFD limits at the service area boundaries are lower than those proposed in section 3.2.1. There are a number of reasons why this may be the case. The most significant factor is likely to be the protection of receivers having higher antenna gains than those that we have assumed. For example, protection of a subscriber receiver having a 33 dBi gain antenna would require a PFD limit of –120.5 dBW/MHz/m$^2$. However, our statistical analysis has shown that the low probability of interference from such a scenario means it is unlikely to be a significant factor in overall network performance. In the case of Canada, it is noted that a second limit of –94 dBW/MHz/m$^2$ is specified as a trigger point for co-ordination with future planned systems; the lower limit is intended only to protect existing systems. It should be noted that, unlike the UK, some of these countries may have a requirement for BWFA systems to co-exist with other types of service which may be more prone to interference, such as point to point links with highly directional antennas.

A further factor is that the limits may include a factor to allow for multiple interferer scenarios. Our analysis has indicated that the probability of multiple interferers being visible to victim receivers under directly aligned, line of sight conditions is small and does not warrant additional tightening of the single interferer limit. Finally, we have assumed that base stations located within 27.5 km of the service area boundary will benefit from up to 9 dB additional shielding due to terrain or antenna discrimination.

# 4. CO-EXISTENCE BETWEEN TWO OR MORE BFWA SYSTEMS OPERATING IN THE SAME GEOGRAPHIC AREA AND IN ADJACENT RADIO SPECTRUM ("SCENARIO 2")

## 4.1 Introduction

In this case significant spatial separation between interferer and victim can not be assumed and co-existence relies upon:

a) frequency separation between interferer and victim

b) frequency discrimination of the transmitter and receiver.

Some parameters for the latter are defined in standards such as EN 301 213, in the form of transmitter spectrum masks and receiver first adjacent channel protection requirements.

It should also be noted that these masks do not allow for frequency tolerances. Tolerances of up to ± 10 ppm are being considered by IEEE 802.16, which could amount to up to 400 kHz at BFWA frequencies. Whilst this is unlikely to be significant for the most broadband systems, it may be necessary to apply additional margins to guard bands, or apply more stringent tolerance requirements, where smaller channel spacings (< 10 MHz) are involved.

This section of the report considers appropriate frequency separation requirements based on currently specified transmitter and receiver characteristics and considers possible improvements to these to facilitate co-existence in the future.

## 4.2 Co-ordination between systems using the same channel spacing

The minimum level of frequency discrimination can be determined to a first approximation by considering the scenario illustrated in Figure 4.1, in which the interferer and victim stations are located 50 metres apart (it is assumed that at smaller distances steps will be taken by operators to avoid direct alignment between antennas).

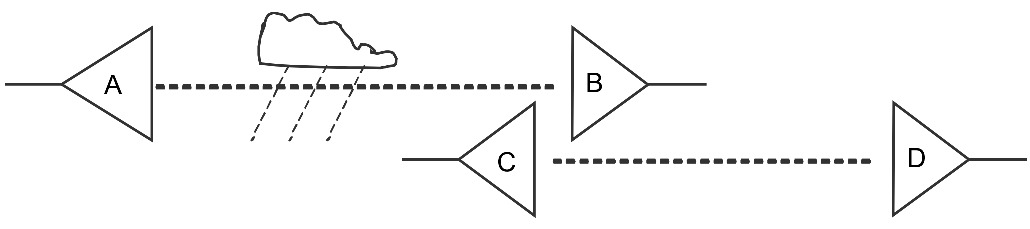



**Figure 4.1: Hypothetical worst case co-located interference scenario**

In this case the link AB is fully faded and B is transmitting at its maximum EIRP level (11.5 dBW/ MHz). D is unfaded and transmitting at an EIRP sufficient to produce a receiver input level at C of 5 dB above threshold, i.e. –120 dBW / MHz. B and C are located 50 metres apart and are directly aligned with each other.

Under co-channel operation, the interference power from transmitter B received at receiver C is:

$P_{rx}$ = 11.5 - FSPL + $G_{rx}$

= 13 - 95 + 33 (f = 27.5 GHz)

**= - 49 dBW / MHz**

This exceeds the wanted signal level from D by 71 dB and the notional interference limit of kTBF-10dB by a factor of 97 dB, implying that a minimum net filter rejection (NFR) of 97 dB would be required to ensure interference free operation even in this worst case scenario. In practice, such levels of NFR are unlikely to be realisable and a small risk of interference between adjacent band services must therefore be tolerated.

The NFR is a function of the transmitter spectrum mask and the receiver filter rejection mask. The transmitter mask is defined in the current ETSI standard for FDMA and TDMA systems using high level and low level modulation schemes. Receiver filter rejection is not defined but may be deduced from the adjacent channel carrier to interference ratio requirement.

Figure 4.2 shows the three EN 301 213 transmitter spectrum masks, normalised to the nominal channel spacing. The generic mask specified by the FCC is also shown for comparison.

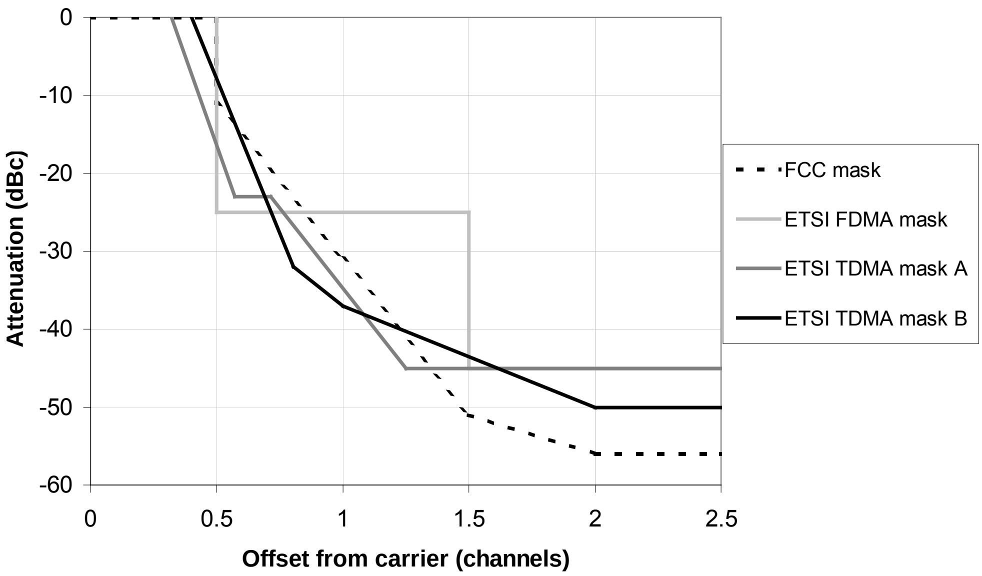



**Figure 4.2: Transmitter spectrum masks defined in EN 301 213**

The above masks imply that there is no further improvement in the filter rejection below the mask floor indicated, regardless of the carrier spacing. In the UK, high density deployments of P-P links in several frequency bands have been successfully co-ordinated based upon figures for NFD derived from equipment spectrum masks taken from the equipment standards and typical receiver offset frequency response characteristics. The transmitter masks in the standards are essentially for conformance test purposes and do not necessarily reflect actual equipment performance. Use of the mask provides over protection particularly at frequency offsets away from the first adjacent channel. Therefore as a compromise UK planning figures were derived after modifying the standard equipment masks with an assumption that the actual emissions continue to roll off to a figure of –70dB relative to the centre frequency (Fc) at the Fc +/- 250% point. This assumption is illustrated in Figure 4.3.

It should also be noted that these masks do not allow for frequency tolerances. Tolerances of up to ± 10 ppm are being considered by IEEE 802.16, which could amount to up to 400 kHz at BFWA frequencies. Whilst this is unlikely to be significant for the most broadband systems, it may be necessary to apply additional margins to guard bands, or apply more stringent tolerance requirements, where smaller channel spacings (< 10 MHz) are involved.

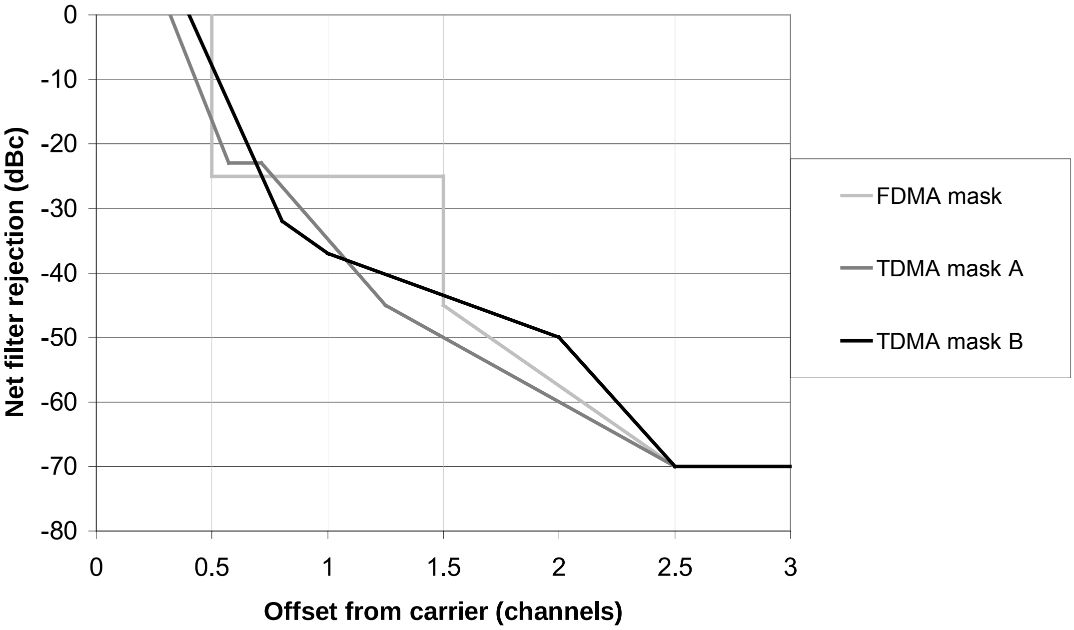



**Figure 4.3: NFR curves based on EN 301 213 spectrum masks and –70 dBc floor**

The co-channel and adjacent channel C/I requirements[9] are:

[9] Although the interferer is on a different channel to the victim, its out of band / adjacent channel emissions will lie within the victim's wanted channel, i.e. from the victim's perspective they add to the co-channel interference. Interference will also be present in the victim's two adjacent channels but will be attenuated by an amount corresponding to the receiver filter rejection at that offset.

| | Co channel | Adjacent channel |
|---|---|---|
| FDMA 4 level modulation | 17.5 | -15.5 dB |
| FDMA 16 level modulation | 26.5 | -6.5 dB |
| TDMA (4 level modulation): | 23 | 0 dB |
| TDMA (16 level modulation): | 30 | 0 dB |

The corresponding receiver threshold levels are:

FDMA 4 level modulation* -124.1 dBW / MHz

FDMA 16 level modulation** -113.7dBW / MHz

TDMA (4 level modulation): -114.5 dBW / MHz

TDMA (16 level modulation): -106.5 dBW / MHz

The maximum cumulative interference levels are therefore:

| | Co channel | Adjacent channel |
|---|---|---|
| FDMA 4 level modulation* | -141.6 | -108.6 dBW / MHz |
| FDMA 16 level modulation** | -140.2 | -107.2 dBW / MHz |
| TDMA (4 level modulation): | -137.5 | -114.5 dBW / MHz |
| TDMA (16 level modulation): | -136.5 | -106.5 dBW / MHz |

*assuming 1.38 bits/ Hz (STM-1 in 112 MHz)

**assuming 2.77 bits / Hz (STM-2 in 112 MHz)

It can be seen that FDMA is more susceptible to co-channel interference than TDMA, whilst TDMA is more susceptible to adjacent channel interference. To determine the minimum separation distance it is therefore necessary to consider two worst case victim scenarios, namely adjacent channel interference into a TDMA receiver and co-channel interference into an FDMA receiver, as a function of interferer carrier frequency separation. Note that since the above interference limits relate to cumulative interference, the adjacent channel limit for a single entry interferer should be reduced by a further 6 dB and the co-channel limit by a further 4 dB[10]. The assumed maximum single entry interference limits are therefore **–120.5 dBW / MHz** (4 level TDMA, adjacent channel) and **–145.6 dBW** (4 level FDMA, co-channel). Figure 4.4 and Figure 4.5 show the interference level vs. separation distance for a variety of carrier frequency separations. Note that an FDMA interferer is assumed in each case as this produces greater out of band emissions (Figure 4.3).

[10] Based on the multiple interferer allowances used in RA Fixed Service frequency assignment criteria

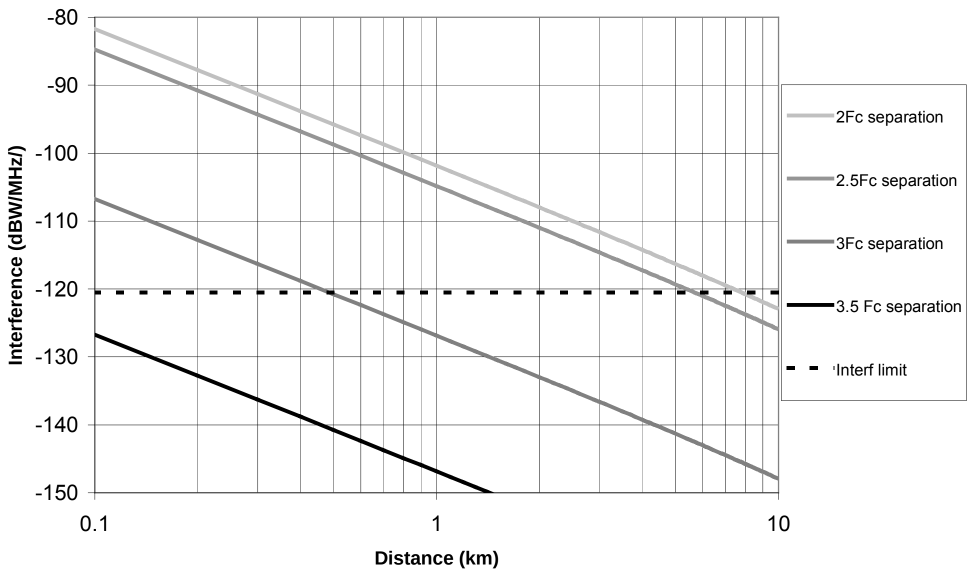



**Figure 4.4: Adjacent channel interference between an FDMA interferer and a TDMA victim, as a function of separation distance and carrier frequency offset**

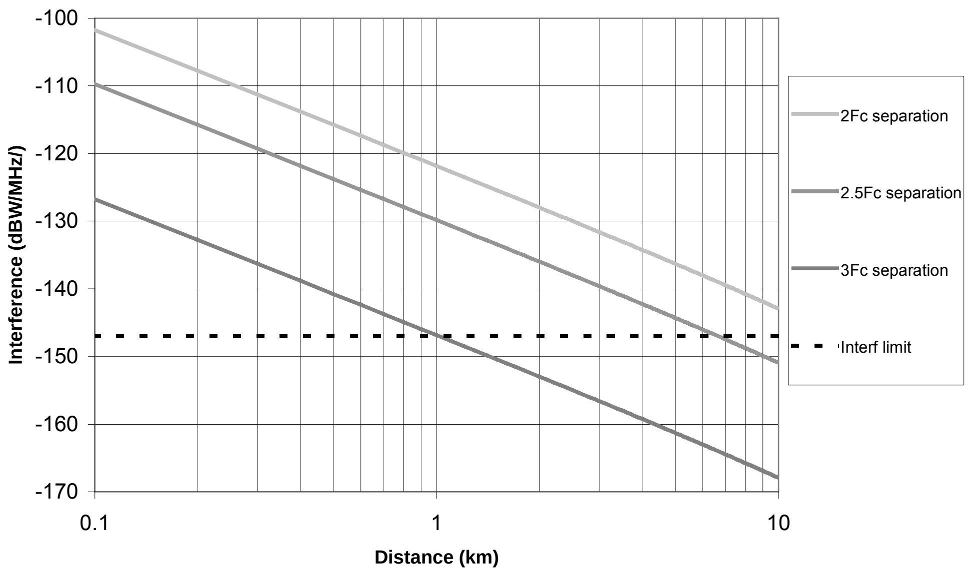



**Figure 4.5: Co-channel interference between an FDMA interferer and an FDMA victim, as a function of separation distance & carrier frequency offset**

Note that in the co-channel interference case (Figure 4.5) the required separation at 3.5 $F_c$ and beyond is the same as at 3 $F_c$, since the –70 dBc floor has been reached at this offset.

Comparing Figure 4.4 and Figure 4.5 shows that the required separation distances are greater in the co-channel case. From Figure 4.5, to meet the co-channel interference criterion between directly aligned subscriber stations at all times a separation distance of 1 km would be required, even with a carrier offset of 3.5 channel spacing or greater. However, it has already been noted that the probability of this worst case scenario arising is remote in practice and the guard band requirement should therefore take account of the statistical spread of interference in a typical co-existence scenario. Figure 4.6 presents interference CDFs for interference between various combinations of interferer and victim. In each case it is assumed that the interferer and victim operate with the same channel spacing and that the net filter rejection is in line with Figure 4.3. A guard band of half the channel spacing is assumed at the edge of each operator's frequency band. It can be seen that only in the case of a high density mesh network interfering with another mesh network subscriber station is the interference limit exceeded in more than one per cent of trials. Interferer densities are 0.009 per $km^2$ for PMP networks and 0.45 per $km^2$ for high density mesh networks.

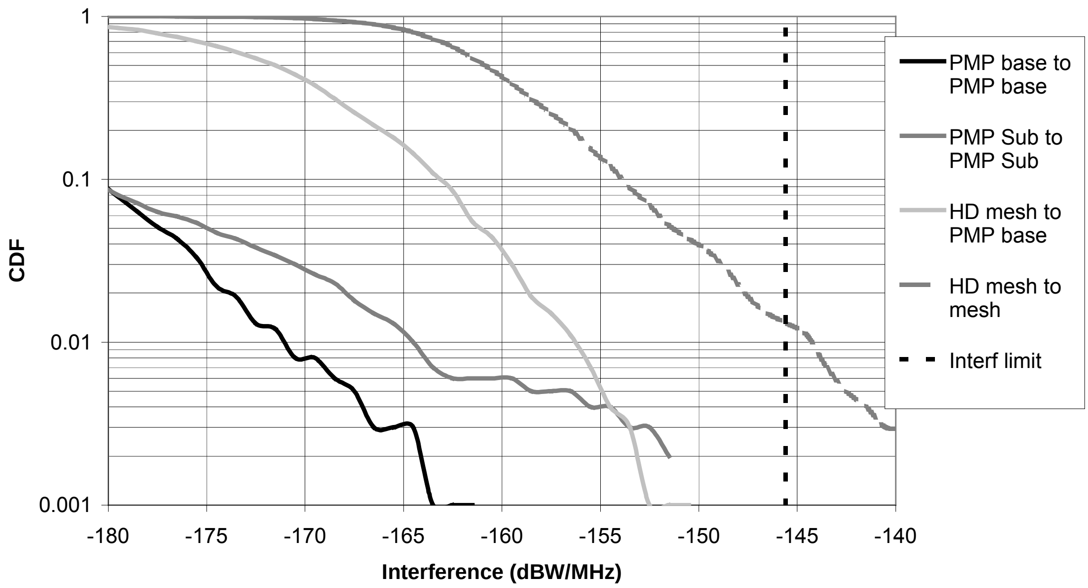



**Figure 4.6: Interference CDFs between networks using identical channel spacings**

Figure 4.6 shows that only one scenario – a high density mesh network interfering into another mesh network receiver – is likely to result in interference above the (kTBF – 10 dB) limit. Even in that scenario, the probability of the limit being exceeded at any given receiver is less than 2 %. In practice, the availability of route diversity and the likelihood that EIRP settings will provide a further link margin of up to 5 dB (section 2.8) means interference is unlikely to be a significant problem in terms of overall network performance.

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

## 4.3 Co-ordination between systems using different channel spacings

Section 4.2 considers the situation where both interferer and victim use the same channel spacing. Under this scenario, the necessary guard band between adjacent services is equally split between the two operators. However, this is not the case when adjacent band services deploy different channel spacings.

Consider the scenario illustrated in Figure 4.7, where two operators are assigned adjacent blocks of spectrum but one decides to implement a 28 MHz channel raster and the other decides upon 112 MHz. To ensure adequate protection of operator A's services, operator B is likely to require a proportionately greater guard band than operators A.

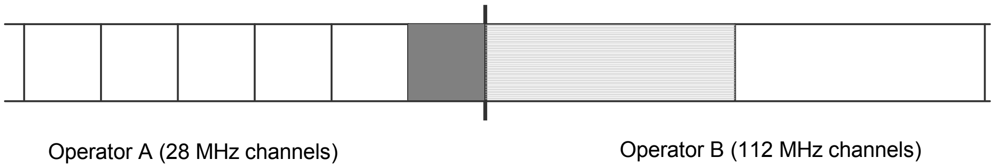



**Figure 4.7: Use of different channel spacings in adjacent bands**

To investigate the implications for typical networks of significant variations in channel spacings, statistical analyses were carried out based on an interferer with four times the channel spacing of the victim. Net filter rejection between the two is assumed to be consistent with Figure 4.3. The following plots show interference CDFs for guard bands per operator of one channel spacing and half the channel spacing.

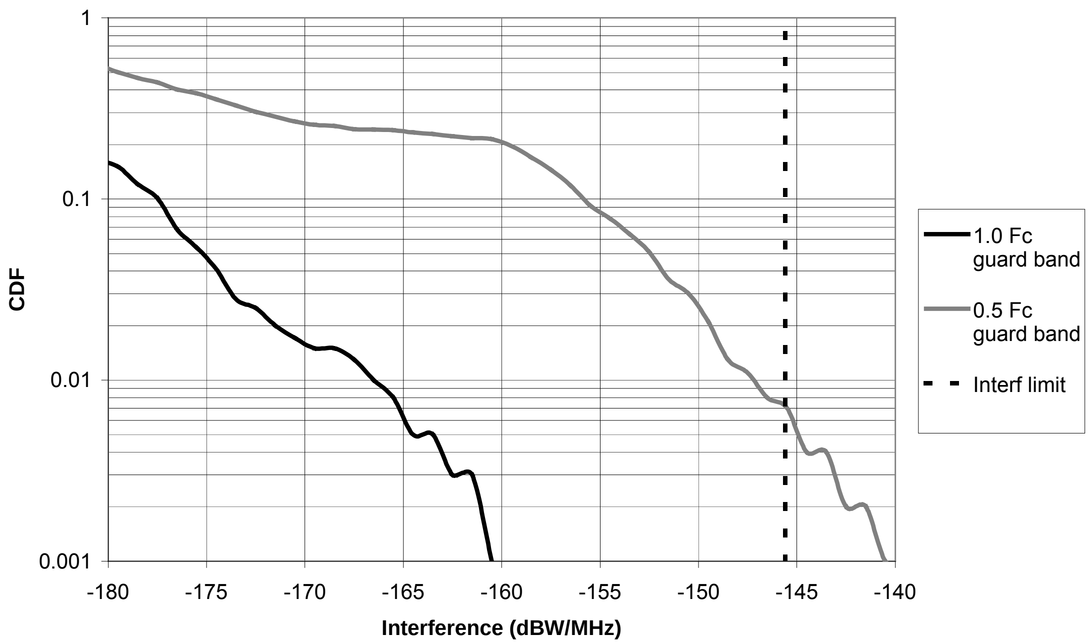



**Figure 4.8: Interference between PMP base stations (interferer density 0.009 per km$^2$)**

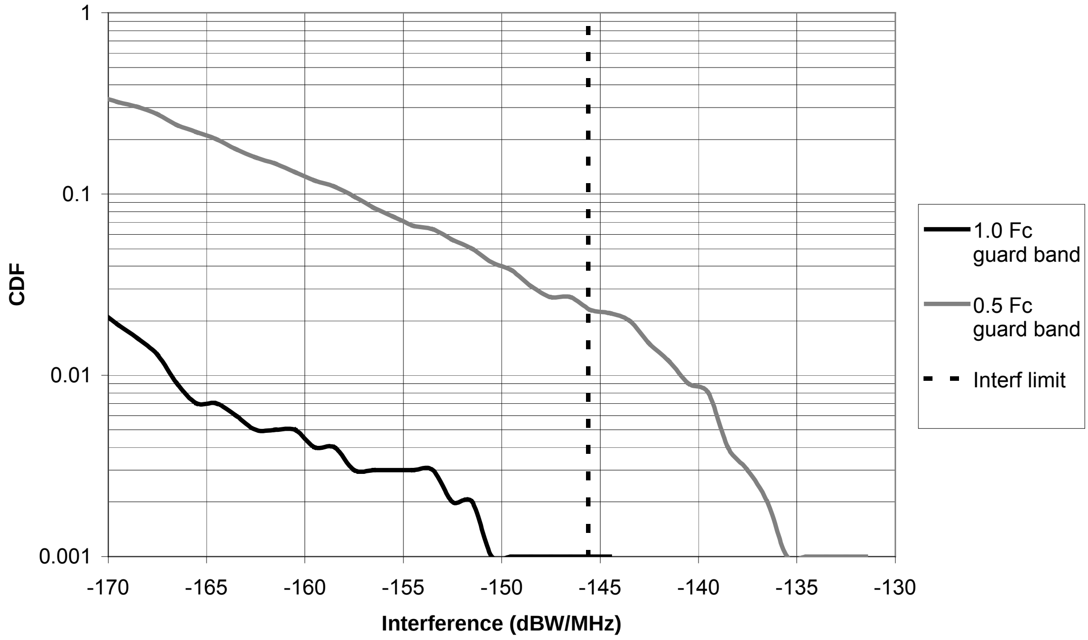



**Figure 4.9: Interference between PMP subscribers (interferer density 0.009 per km$^2$)**

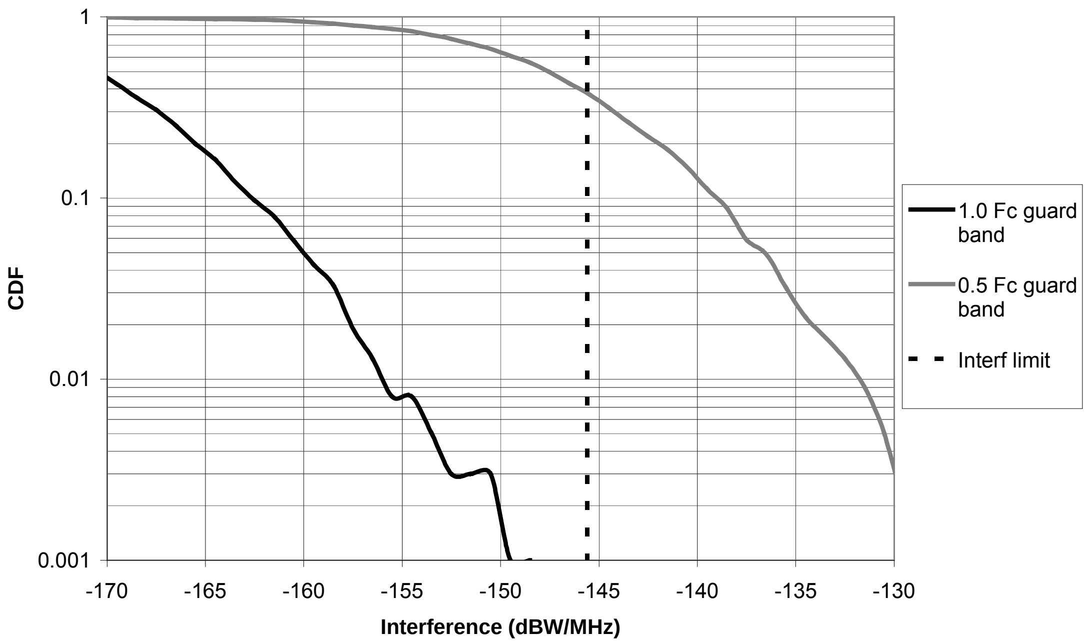



**Figure 4.10: Interference between high density mesh network and PMP base station (interferer density 0.45 per km$^2$)**

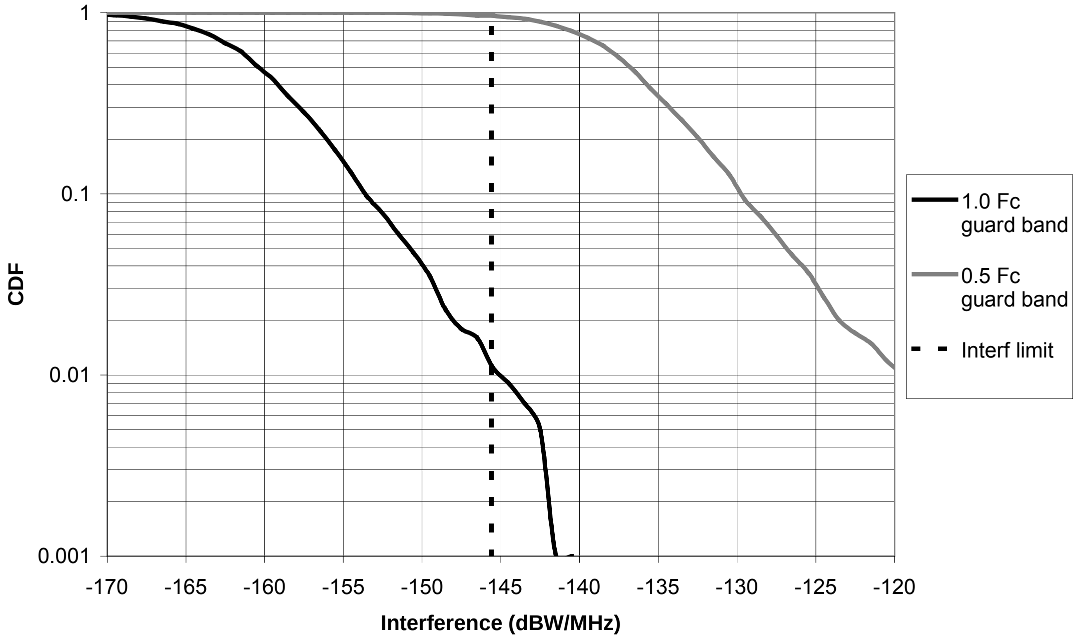



**Figure 4.11: Interference between high density mesh networks (interferer density 0.45 per km$^2$)**

It can be seen that the increased bandwidth of the interferer leads to a significant increase in the interference level at the edge of the adjacent band. To ensure substantially interference free co-existence between two networks where there is a significant difference in the channel spacings deployed, a guard band equal to a single channel spacing will need to be accommodated within each operator's band.

Guard bands may still be used on a co-ordinated basis for specific applications where the risk of interference is minimal, for example to provide spur or repeater links to subscribers outside the reach of the main network base stations, or for provision of very short links in urban areas with a significant amount of shielding. **Polarisation discrimination may provide a means for operators to reduce further the need for individual station co-ordination (each operator could elect to use exclusively horizontal or vertical polarisation on the channels being co-ordinated).**

## 4.4 Note on NFR assumptions and current ETSI standards

The above analyses are based on the assumption that a minimum net filter rejection of 70 dB exists between the transmitter and receiver at a frequency offset of 2.5 times the channel spacing (2.5 $F_c$) or greater. It is assumed that IF and baseband processing will provide sufficient receiver discrimination at greater carrier offsets, although it is noted that the + 30 dBc receiver CW interference requirement does not apply within $\pm$ 5 $F_c$. The NFR is therefore dominated by the emission characteristics, namely the spectrum mask and spurious emissions. Both of these as currently specified permit significantly higher out of band emissions than those assumed in the above calculations.

The current ETSI standard defines transmitter spurious emission limits as -60 dBW/ MHz, equivalent to an EIRP of –27 dBW / MHz for our reference 33 dBi subscriber antenna. This is equivalent to -38.5 dBc assuming an 11.5 dBW / MHz wanted EIRP. This exceeds the current transmitter mask floor, which itself falls considerably short of the –70 dBc assumed above, by a substantial margin. **Whilst our assumed NFR values are considered to be realistic, if emissions comparable to those currently specified were to arise over significant portions of the band, interference levels could increase by as much as 20 dB.**

Manufacturers and operators should therefore be encouraged to minimise out of band emissions. Clearly there is a balance to be struck between the additional cost and complexity which may result and the benefits in terms of reduced interference risk. **Two reasonable measures which should be considered within the standards fora are the reduction of the transmitter mask floor in line with the current FCC mask (-56 dBc) and the extension of the receiver CW interference rejection requirement to cover carrier offsets beyond ± 2.5 $F_c$, rather than the current ± 5 $F_c$.**

# 5. INTERFERENCE TO RADIO ASTRONOMY AT 43 GHZ

The band 42.5 - 43.5 GHz is allocated, with primary status, to the Radio Astronomy service, and S5.149 urges administrations to '*take all practicable steps to protect the radio astronomy service from harmful interference*'.

The band is not currently known to be used in the UK. It is, however, noted in the current CRAF[11] handbook [1] that the band may, in the future, be used for spectral line observations by the MERLIN interferometer network in North-West England, and for other planned studies of the spectral lines of Silicon Monoxide. Footnote S5.149 indicates that the sub-bands 42.77-42.87 GHz, 43.07-43.17 GHz and 43.37-43.47 GHz are used for such spectral line observations.

In addition to spectral line observations, astronomers also need to characterise the shape of continuum emission curves from astronomical gasses and objects. To allow such characterisation, it is necessary to sample the spectrum at approximately octave intervals, and the 43 GHz band is one of the bands preferred for this purpose. Measurements of wideband (continuum) radiation are generally more susceptible to interference than are spectral line observations, as the sensitivity of the RA receiver will generally be greater, due to the larger bandwidth that may be used for observing.

The most sensitive observations are those carried out by single element ('total power') telescopes, as interference at different elements of an interferometer will generally be somewhat de-correlated, and therefore partially rejected.

ITU-R RA.769-1 gives example limits for interference thresholds for total power observations, based on an interference component equal to 10% of the measurement uncertainty due to noise in the telescope receiver. For 43 GHz, the relevant pfd limits are:

- Continuum: -167 $dBW/m^2$.MHz
- Spectral line: -150 $dBW/m^2$.MHz

The band is also likely to be used for Very Long Baseline Interferometry (VLBI) where the elements of the interferometer are observatories separated by continental distances. For a VLBI network, there will be no possibility of correlation between the terrestrial interference received at different observatories, and the overall instrument will therefore be relatively insensitive to interference.

The interference threshold for a VLBI element is based on a level of 1% of the receiver noise power (rather than the fluctuations in this power). The threshold is -113 $dBW/m^2$.MHz, more than 50dB greater than for the total-power, continuum case.

[11] Committee on Radio Astronomy Frequencies, CRAF Handbook for Radio Astronomy, 2nd Edition, 1997

For an interfering transmitter eirp of 0.5 dBW/MHz, example separation distances were calculated using ITU-R P.452-9 and assuming a smooth-Earth:

| Observation | Loss required | P.452-9 distance (10%) | P.452-9 distance (50%) |
|---|---|---|---|
| Continuum | 221.6 dB | 88 km | 60 km |
| Spectral line | 204.1 dB | 49 km | 40 km |
| VLBI | 167.1 dB | 32 km | 29 km |

It can be seen that a requirement to offer protection to UK radio astronomy sites, to the levels recommended in ITU-R RA.769 may require substantial exclusion zones, subject to more detailed analysis as more information becomes available regarding actual BFWA deployment scenarios.

# 6. CONCLUSIONS AND RECOMMENDATIONS

## 6.1 Co-ordination requirements for adjacent geographic areas

### 6.1.1 Boundary Power Flux Density limit for co-ordination

Our investigations have concluded that individual BFWA transmitters should be co-ordinated when the **PFD** generated at the network's service area boundary exceeds the following values:

**42 GHz: -98.5 dBW/MHz/m$^2$**

**28 GHz: - 102.5 dBW/MHz/m$^2$.**

### 6.1.2 PMP Base Stations

For a PMP **base** station transmitter generating an EIRP of 0.5 dBW / MHz (= 15 dBW in 28 MHz bandwidth), these PFD limits correspond to maximum co-ordination distances from the service area boundary of:

**42 GHz: 18 km**

**28 GHz: 27.5 km**

These maximum co-ordination distances are those at which co-ordination will be required under free space propagation conditions and are functions of EIRP, as shown in Figure 3.5 (42 GHz) and Figure3.8 (28 GHz). These are also the minimum distances at which a base station receiver with a directly aligned line of sight path towards the network service area boundary and a 15 dBi gain antenna will be protected against interference from individual interferers in adjacent networks.

Without co-ordination, protection from interference at locations closer to the boundary will require a reduction in the antenna gain in the direction of the boundary, or additional path loss between the receiver station and the boundary, in accordance with Figure 3.4 (42 GHz) or Figure 3.9 (28 GHz).

### 6.1.3 Subscriber Stations (PMP and Mesh)

Where uplink ATPC is deployed, and assuming a maximum transmitter EIRP of 11.5 dBW / MHz, the maximum co-ordination distances from the network service area boundary for PMP **subscriber** stations and mesh network **node** stations are:

**42 GHz**: **10 km**

**28 GHz**: **16 km**,

It is recommended that, to avoid interference from or between high density subscriber networks, operators in adjacent service areas should **avoid co-channel, co-polar operation within 5 km** of their network service area boundaries.

#### 6.1.4 Effect of Multiple Interferers

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 will ensure substantially interference free co-existence between adjacent service areas for both PMP and mesh architectures.

#### 6.1.5 Service Area Boundaries

It is recommended that licence area boundaries should, as far as possible, avoid major population centres to minimise the need to co-ordinate large numbers of stations. There is also likely to be merit in aligning boundaries with significant terrain features where these lie between major population centres.

### 6.2 Co-ordination requirements for adjacent band working in the same geographic area

On the basis of current technology, as typified by receiver and transmitter characteristics specified by ETSI and the FCC, we recommend that:

- a co-ordination guard band equal to one channel spacing should be required at the edges of each operator’s spectrum assignment. This will permit co-existence between operators even when there is a significant difference in the channel bandwidth of the two networks. Transmissions will be viable within this guard band subject to co-ordination between operators. Such co-ordination for example could be based on the use of orthogonal polarisation or by agreement on an area by area basis. Alternatively the guard bands may be suitable for conveyance of narrower bandwidth signals, e.g. for network control purposes or voice telephony.
- Where two networks share the same channel bandwidth, the co-ordination guard band may be reduced to half the channel spacing.

It is further recommended that, to minimise the risk of interference between services in adjacent bands, the following two modifications should be considered by the relevant standards bodies:

- reducing the transmission mask floor from the current –45 / -50 dBc level to the –56 dBc level specified by the FCC.
- extending the + 30 dBc CW interference requirement for BWFA receivers to all carrier offsets beyond $\pm$ 2.5 times the carrier spacing, rather than beyond $\pm$ 5 times as currently specified.

# 7. ACKNOWLEDGEMENTS

The authors are grateful for the assistance of the following companies and organisations in providing information used in this report:

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Danish National Telecom Agency

Federal Communications Commission

Hughes Network Systems

Industry Canada

Nortel Networks Europe

Plextek

German Reg TP

Radiant Networks

Spectrapoint

Wavecom Electronics Inc

# 8. GLOSSARY

| | |
|---|---|
| BFWA | Broadband Fixed Wireless Access |
| CDF | Cumulative Distribution Function |
| CEPT | Conference of European Post and Telecommunications Administrations |
| C/I | Carrier to Interference Ratio |
| CW | Continuous Wave |
| EIRP | Effective Isotropically Radiated Power |
| ERC | European Radiocommunications Committee |
| ETSI | European Telecommunications Standards Institute |
| FDMA | Frequency Division Multiple Access |
| FSPL | Free Space Path Loss |
| FSK | Frequency Shift Keying |
| IEEE | Institution of Electrical and Electronic Engineers |
| IF | Intermediate Frequency |
| ISDN | Integrated Services Digital Network |
| PSK | Phase Shift Keying |
| PSTN | Public Switched Telecommunications Network |
| QPSK | Quaternary Phase Shift Keying |
| RA | UK Radiocommunications Agency |
| S/N | Signal to Noise Ratio |
| TDMA | Time Division Multiple Access |

# ANNEX A: SUMMARY OF EN 301 315 PARAMETERS

## A.1. General

Maximum mean transmitter output power (all stations): + 5 dBW (this is the power into the antenna feed)

## A.2. Frequency Division Multiple Access (FDMA) systems

Channel capacity (112 MHz): STM-1 (4-state modulation); STM-2 (16-state modulation)

Transmitter spectrum mask: see figure A1 below (based on 112 MHz channel spacing, scale accordingly for smaller channel spacings)

Receiver input level for BER = $10^{-6}$: -125.5 + 10 log b dBW (4 state modulation);
- 119.5 + 10 log b dBW (16 state modulation), where b = bit rate in Mbit/s.

Co-channel carrier to interference (C/I) limit for 1 dB degradation in 10-6 BER threshold:
17.5 dB (4 state modulation); 26.5 dB (16 state modulation).

Adjacent channel limit for 1 dB degradation in 10-6 BER threshold:
-15.5 dB (4 state modulation); -6.5 dB (16 state modulation).

## A.3. Time Division Multiple Access (TDMA) systems

Minimum gross bit rate (112 MHz): 128 Mbit/s (type A); 256 Mbit/s (type B). Although it is not specified, it is assumed that type A refers to 4-state modulation and type B to 16-state modulation.

Transmitter spectrum mask: see fig A1 below (based on 112 MHz channel spacing).

Receiver input level for BER = $10^{-6}$ (112 MHz): -94 dBW (type A); -86 dBW (type B).

Co-channel carrier to interference limit for 1 dB degradation in $10^{-6}$ BER threshold: 23 dB (type A); 30 dB (type B).

Adjacent channel C/I limit for 1 dB degradation in $10^{-6}$ BER threshold: : 0 dB (types A & B)

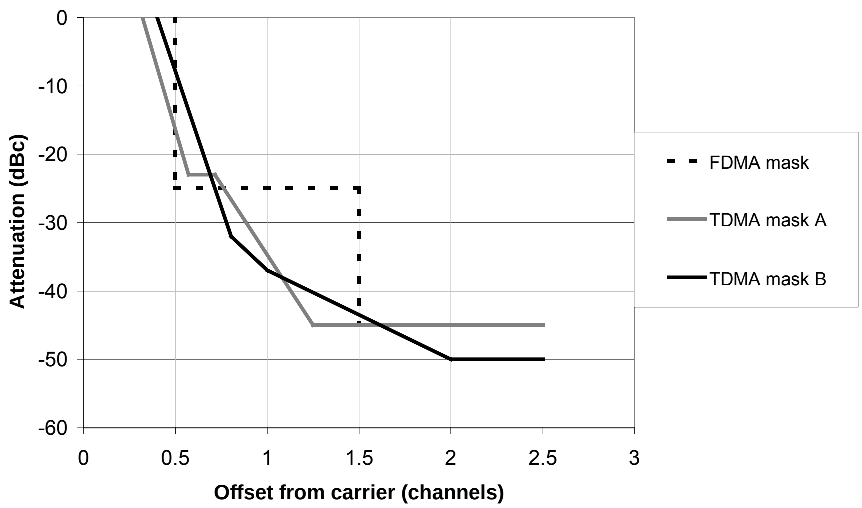


**Figure A.1: EN 301 213 transmitter spectrum masks**

# ANNEX B: SUMMARY OF IEEE 802.16 ACTIVITIES ON CO-EXISTENCE

The IEEE 802.16 Working Group on Broadband Wireless Access standards was established in March 1999 "to develop standards and recommended practices to support the development and deployment of fixed broadband wireless access systems." The co-existence task group is developing a Recommended Practice for the design and co-ordinated deployment of BFWA systems to minimise interference so as to maximise system performance and/or service quality.

A number of papers addressing specific co-ordination issues have been published via the task group, whose aim is to complete its work substantially by March 2000. The main findings of the group so far are summarised below.

## B.1. Automatic Transmitter Power Control (ATPC)[12]

As a general rule downstream transmissions in PMP BWFA networks do not deploy ATPC. This is because of the shared nature of the downstream signal, which is effectively “broadcast” to all users within a cell (although only individual users may be able to access data at any given time). It is also argued (perhaps less than convincingly) that deployment of ATPC can degrade intra-system C/I levels under differential rain fade conditions. Downstream ATPC is used in some mobile applications (e.g. GSM) to reduce inter-cell interference, and its future deployment in BWFA systems could significantly reduce the probability of interference between adjacent networks’ base stations, particularly where the networks are operating unsynchronised TDD. However on the basis of current practice it must be assumed for co-ordination purposes that PMP base stations transmit at full power continuously.

Conversely, upstream PMP transmissions universally employ ATPC, to ensure a consistent receive signal level from each subscriber in the cell. Among the reasons cited for ATPC deployment are:

- To minimise the required adjacent channel rejection of the base station receiver
- To minimise the required adjacent channel emission suppression of the subscriber transmitters
- To minimise the required out of sector base station antenna rejection.

Whilst relaxation of these parameters leads to simpler and cheaper network roll out, there effect is to increase susceptibility to interference from adjacent networks, particularly interference between base stations where the relaxation is not balanced by a reduction in the mean interference power.

The nominal receive signal level at the base station is set typically up to 5 dB above the receiver threshold (usually defined in terms of a $10^{-6}$ bit error rate). This provides

[12] “Power Control Assumptions for Co-existence modelling”, Howard Sandler, Nortel Networks, September 1999

a margin for imperfect power control loops or imprecise power measurements as well as ensuring substantially error free operation for most of the time. A typical rain fade margin of 20 dB is currently proposed, resulting in a 15 dB reduction (i.e. 20 –5) in subscriber station EIRP under unfaded conditions.

## B.2. Propagation Model[13]

The current 802.16 proposal is to assume free space, with largely uncorrelated rain fading on wanted and interfering paths. Taking account of the typical spatial distribution of rainfall and the effect of airborne water vapour that is likely to affect the interfering path when rain is present on the wanted path, an additional attenuation of 0.2 dB/km may be assumed for the interfering path when the wanted path is fully faded due to rain.

## B.3. Interference Mitigation Techniques[14]

A number of potential mitigation techniques are proposed in this paper. The most obvious is ensure an adequate separation distance between interferer and victim, or to lower the transmitter power of the interferer. The latter would of course reduce the maximum available cell size for the interferer network, which could be problematic as cells are likely to be larger towards the edge of coverage areas where population density is lower. Antenna orientation (azimuth pointing and downtilt) can also be used to minimise “spillover” outside the intended coverage area. In particular, base station sectors close to service area boundaries and pointing in the direction of adjacent service areas should be avoided. Reducing the height of an interferer or victim base station antenna may also be feasible in some instances, although this will usually be at the expense of available cell size. In the longer term techniques such as adaptive antenna arrays, beam or null steering may be adopted to minimise the effects of interference and may lead to reduced dependence upon inter-operator co-ordination.

Polarisation is a particularly effective discriminant between co-channel services (although at higher frequencies the benefit can be diminished by the depolarising effect of rain scatter). Under optimal conditions 25 – 30 dB of cross polar discrimination can be achieved using current antenna technology. The use of more robust coding and modulation schemes such as spread spectrum or COFDM may also provide benefits in the future, although these are not under active consideration currently.

Partitioning of spectrum between adjacent operators is considered very much a last resort.

[13] “Propagation Model for Co-existence Modelling”, Howard Sandler, Nortel Networks, September 1999

[14] “Proposed draft text for the Coexistence Practice Document on Mitigation Techniques”, Rebecca Chan, Industry Canada, September 1999.

# ANNEX C: GLOBAL STATUS OF BFWA CO-ORDINATION AND STANDARDS ACTIVITY

This section reviews current international activities addressing co-ordination and co-existence requirements for BFWA systems.

## C.1. National Administrations

A number of countries are currently in the process of introducing BFWA services and have considered how co-ordination between adjacent licensing regions might be carried out. Perhaps the most advanced in terms of system roll out is the USA, although Australia, Canada and Switzerland have also developed their own approaches to co-ordination. The following sections review the approaches taken in each of these countries.

### C.1.1 USA

Co-ordination requirements for Local Multipoint Distribution Systems (LMDS) in the USA are defined by the Federal Communications Commission (FCC)[15]. Co-ordination must be carried out whenever a transmitter is located within 20 km of a licensed area boundary. Co-ordination comprises two separate elements, namely notification by the operator of the potentially interfering system and response by those who may be affected. The notification procedure involves providing the following technical information:

- transmitter location, frequencies and polarisation
- equipment type, stability, output power, ITU emission code and modulation scheme
- antenna type, gain and radiation pattern
- antenna height above ground and sea level
- path azimuth and distance from boundary
- estimated transmission line loss

The onus is then on the respondent(s) to identify, within a 30-day period, any potential interference problem that may arise. The FCC requires “every reasonable effort” to be made by all parties to eliminate problems and conflicts. Emission limits for LMDS systems are also defined, in terms of a generic transmitter spectrum mask and transmitter power or effective isotropically radiated power (EIRP) limits for the base and subscriber stations (see section 2.4.6).

[15] Federal Code of Regulations title 47 (47 CFR), chapter 1, § 101.103

### C.1.2 Australia

The Australian administration does not specify co-ordination distances for BFWA services at 28 GHz, but requires[16] that operators set back receivers from the licensed area boundary to ensure protection from adjacent region interference. EIRP limits are defined in the operators' licences but transmitters may be operated at this maximum power anywhere within the licensed area.

### C.1.3 Canada

The Canadian Government has designated six spectrum blocks of 500 MHz each in the 26-28 GHz band for BFWA systems. Provision has also been made for the introduction of BFWA services into the 38 GHz band, alongside existing point to point radio relay services. The following technical criteria have been defined[17] for co-ordination purposes where the boundaries of adjacent licensed areas are within 60 km of one another and base stations are situated at least 4 km within the boundaries.

i.) where the power flux density (PFD) generated by a proposed transmitter is less than –114 dBW/MHz/m$^2$ (28 GHz) or –125 dBW/MHz/m$^2$ (38 GHz) at the adjacent service area boundary, no co-ordination is required

ii.) where the PFD is between –114 and –94 dBW/MHz/m$^2$ (28 GHz) or between –125 and –105 dBW/MHz/m$^2$ (38 GHz) at the adjacent service area boundary, co-ordination is required with existing fixed service installations

iii.) where the PFD exceeds –94 (28 GHz) or –105 dBW/MHz/m$^2$ (38 GHz) at the adjacent service area boundary, co-ordination with both existing and planned systems is required.

The limits are believed to be tighter at 38 GHz because of the need to co-exist with highly directional point to point links.

These co-ordination criteria apply only when an alternative multilateral agreement between operators is not in place. The 60 km separation criterion is based on the radio horizon between transmitter and receiver antennas located 90 m above ground level with an average clutter height of 15m. Operators are required to calculate the PFD at the service area boundary of neighbouring service areas for each transmitter. The calculated PFD should take into account all propagation losses, antenna directivity and earth curvature. The PFD level at the service area boundary shall be the maximum value for elevation points up to 500 m above local terrain elevation.

EIRP spectral density must not exceed 30 dBW/MHz for subscriber stations and 14 dBW/MHz for base stations. There is no limit on total EIRP other than the 55 dBW required by the ITU Radio Regulations limit.

[16] Radiocommunications (Unacceptable Levels of Interference - 28 GHz and 31 GHz bands) Determination, Australian Communications Authority, 11th November 1998

[17] "A Radio Advisory Board of Canada supporting study leading to a co-ordination process for point-to-multipoint broadband fixed wireless access systems in the 24, 28 and 38 GHz bands", July 1999.

### C.1.4 Germany

A competition for regional BFWA licences throughout Germany was recently undertaken. A total of 413 regions were defined, of which 262 attracted sufficient interest to warrant a competition (licences were awarded on a non-competitive basis in the remaining regions). In each region a number of spectrum blocks were available. To avoid interference between operators, guard bands of 28 MHz are required between blocks. Inter-region interference is managed by application of a blanket PFD limit of –110 dBW/MHz/$m^2$ at a distance 15 km from the service area boundary[18].

### C.1.5 Switzerland

The Swiss Office fédéral de la communication (Ofcom) recently issued a consultation document[19] proposing the allocation of frequencies for BFWA in the 26 GHz band at the end of 1999. Nine licensing regions are proposed, based mainly on topography (where practical, boundaries are concurrent with mountain ridges to provide additional protection). A standard "protection zone" between adjacent regions of 15 km is proposed, equally divided between the two. The PFD outside the protection zones in the neighbouring regions must not exceed –110 dBW/MHz/$m^2$.

## C.2. Standards and Regulatory Bodies

### C.2.1 IEEE 802.16 Co-existence task group

The IEEE 802.16 Working Group on Broadband Wireless Access was established in March 1999 with a brief to develop standards and recommended practices to support the development and deployment of BFWA systems in the frequency range 10 – 66 GHz. The Co-existence task group is developing a "Recommended Practice" for the design and co-ordinated deployment of BFWA systems to minimise interference so as to maximise system performance and/or service quality.

A number of papers addressing specific co-ordination issues have been published via the task group, whose aim is to complete its work substantially by March 2000. The main findings of the group at the time of writing are summarised in annex B of this report.

### C.2.2 ETSI

Work on BFWA systems is being addressed in two ETSI fora, namely the Broadband Radio Access Networks (BRAN) project and sub-technical committee TM4 (Transmission & Multiplexing, Fixed Radio Systems).

[18] Source: Reg TP

[19] "Wireless Local Loop: consultation on requirements", May 1999

The BRAN project is addressing wireless access systems with bit rates of 25 Mbit/s or more and operating in either licensed or licence-exempt spectrum. Included within its remit is development of the HIPERACCESS standard, intended for wide area point-to-multipoint, high speed access (25 Mbit/s typical data rate) by residential and small business users. HIPERACCESS is intended to provide connectivity to a wide variety of networks including UMTS core networks, ATM networks and IP based networks.

TM4 recently initiated a new work item entitled "Transmission and Multiplexing Radio Equipment used in Multimedia Wireless Systems (MWS) in the band 40.5 GHz to 43.5 GHz". The work is being supported by a number of key players in BFWA development, including Hughes Network Systems, Radiant Networks PLC, Bosch Telecom GmbH, Nortel Networks and Lucent Technologies. The scope of the work item is defined as:

*"Equipment performance characteristics and parameters necessary to facilitate coexistence between broadband Multimedia Wireless Systems (MWS) in either adjacent frequency assignments in the same geographical area or co-frequency assignments in neighbouring geographical areas."*

The timescale for production of the first draft is December 1999 with a target publication date for the standard of March 2001.

Currently there are two draft ETSI standards relating to BFWA networks, both based on PMP technology. These are:

- **EN 301 213** (Point-to-multipoint digital radio relay systems in frequency bands in the range 24.25 GHz to 29.5 GHz using different access methods), and
- **EN 301 215** (Antennas for use in point-to-multipoint digital radio relay systems in the 11 GHz to 60 GHz band)

Neither of these standards currently addresses frequencies above 30 GHz (EN 301 215 is intended to cover frequencies up to 60 GHz and work on the final section addressing frequencies above 30 GHz has recently commenced in TM4). EN 310 213 is largely based on existing point to point standards, assuming similar modulation, multiple access and RF channelisation schemes.

The outcome of the new work item in TM4 is likely to have a significant bearing upon future BFWA systems. Initial indications are that the underlying technical assumptions will not differ significantly from those in EN 301 213, hence there are unlikely to be significant changes to transmitter spectrum masks or receiver characteristics. However, the work item does provide an opportunity to introduce refinements that may facilitate co-existence such as improved transmitter or receiver filtering.

### C.2.3 CEPT ERC

BFWA spectrum and co-existence issues are being addressed principally within three ERC project teams, namely:

- FM (Frequency Management) PT 29 (MMDS, MVDS and MCS),
- FM PT 34 (High density applications in the fixed service), and
- SE (Spectrum Engineering) PT 19 (Fixed service issues)

PT FM 29's remit is to identify candidate bands for harmonised BFWA spectrum allocations within Europe. As a result of the PT's work ERC Decision **CEPT/ERC/DEC(99)15** was adopted on 1 June 1999 , covering the designation of the harmonised frequency band 40.5 to 43.5 GHz for the introduction of Multimedia Wireless Systems (MWS), including Multipoint Video Distribution Systems (MVDS)

PT FM 34 is addressing inter-service sharing issues affecting both BFWA and narrow band WFA services. PT SE 19 is also addressing these issues from a spectrum engineering perspective, and is co-ordinating work on intra-service coexistence issues relating to BFWA

As part of its work addressing inter-service sharing issues, SE 19 produced a number of reference system parameters representing various possible types of BFWA system. These are summarised in section 2.4.4 of this report.

### C.2.4 EU Funded Research Programmes

There are two EU funded projects under the ACTS initiative that are relevant to BFWA. These are CRABS (Cellular Radio Access for Broadband Services) and CABSINET (Cellular Access to Broadband Services and Interactive Television).

The main objective of CRABS is to develop representative demonstrator broadband fixed cellular systems. The project involves detailed studies of system architectures, frequency planning and spectrum engineering. Trials have taken place or are planned in the UK, Czech Republic, Greece, Italy and Norway. A brief description of the UK trial can be found in section 2.5.1 of this report. Work so far appears to confirm the commercial and technical viability of deploying multimedia wireless systems in the 42 GHz band. CRABS has also carried out practical trials relating to coverage and propagation that have been used in the preparation of a draft ITU-R Recommendation on propagation prediction methods for millimetre wave fixed access networks (see section 2.7),

CABSINET aims to define and demonstrate a BFWA network for coverage of the "last mile" in urban and rural environments. The intention is to provide fixed reception at frequencies around 40 GHz using a rooftop antenna, with localised mobile coverage being provided at 5.8 GHz. Target applications include generic wireless access services for residential or business customers supporting interactive television services and access to the Internet. Again, work so far in CABSINET appears to confirm the viability of offering BFWA services at 42 GHz. One interesting technological development that is being addressed in CABSINET is the transmission of Coded Orthogonal Frequency Division Multiplex (COFDM) signals at 42 GHz. If successful this could have positive implications for adjacent band co-existence, since the out of band emissions are much reduced relative to conventional digital modulation schemes. There is little evidence however that this technology will be adopted in commercial systems at these frequencies in the foreseeable future.

# ANNEX D: MONTE CARLO SIMULATION METHODOLOGY

The Monte Carlo simulation module, part of the Aegis Systems Spectrum Engineering Toolkit (ASSET), enables assessment of the impact of multiple interfering sources. During the simulation, for each of a large number of trials (typically 1,000), a population of interfering transmitters is randomly located, at a specified geographic density, within a 'cell' of a specified radius. An exclusion zone around the centre of the cell may also be specified to avoid unrealistically close transmitter-receiver spacings.

A single victim receiver is then positioned as required. If the simulation concerns networks sharing the same geographic area, the victim receiver is assumed to be at the interferer 'cell' centre. If the simulation is addressing interference between cells, the victim is assumed to be located outside the cell, as shown in figure D.1 below.

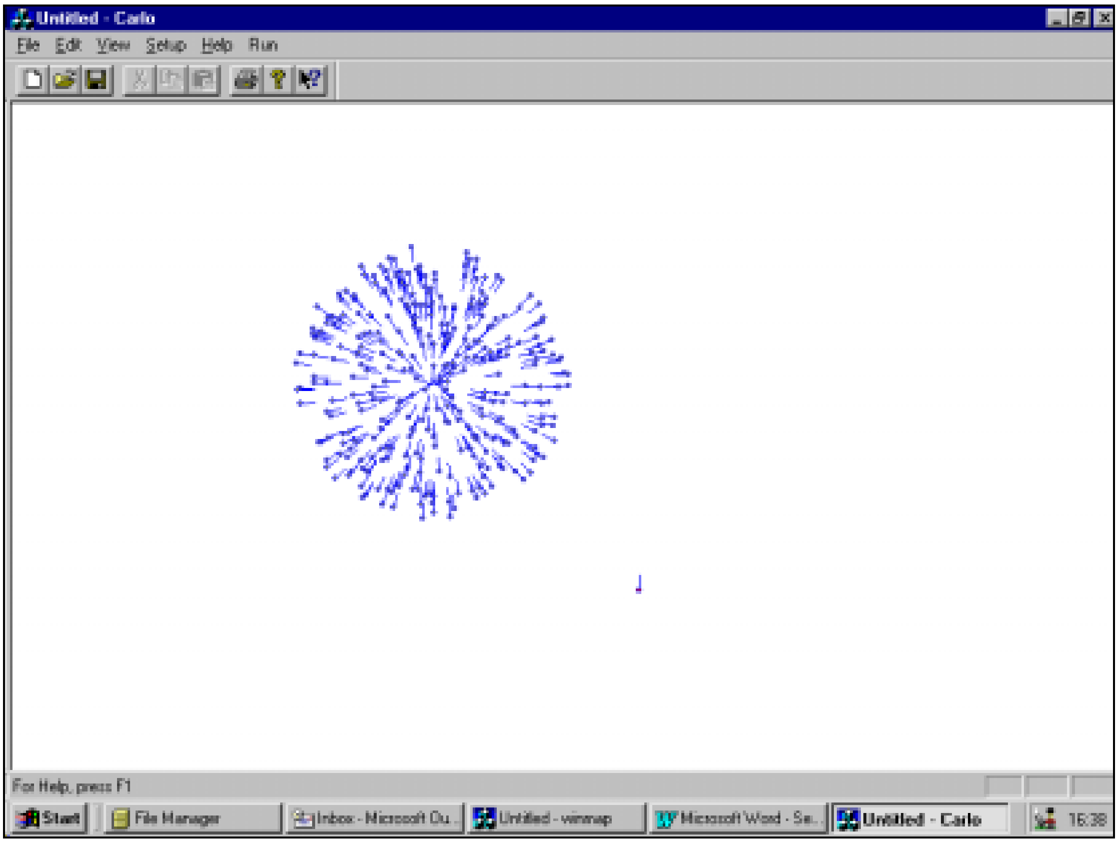


**Figure D.1 Screen shot from Ægis Systems Spectrum Engineering Took Kit (ASSET) Monte Carlo module (subscriber to base station interference scenario, adjacent geographic areas)**

In figure D.1, all interfering subscriber stations are aligned towards the base station located at the centre of the cell. Individual interferers are randomly located and their EIRPs set according to their distance from the base station. The software can also model mesh networks, by assuming a random interferer pointing azimuth and EIRP.

The antenna pattern of each transmitter and receiver may be modelled using either standard patterns such as ITU-R F 1245, or may be read from a user-specified pattern. The latter technique was used in the simulations that follow, to enable patterns based on EN 301 215 to be applied. An illustration of how the data is entered into the programme is shown in figure D.2

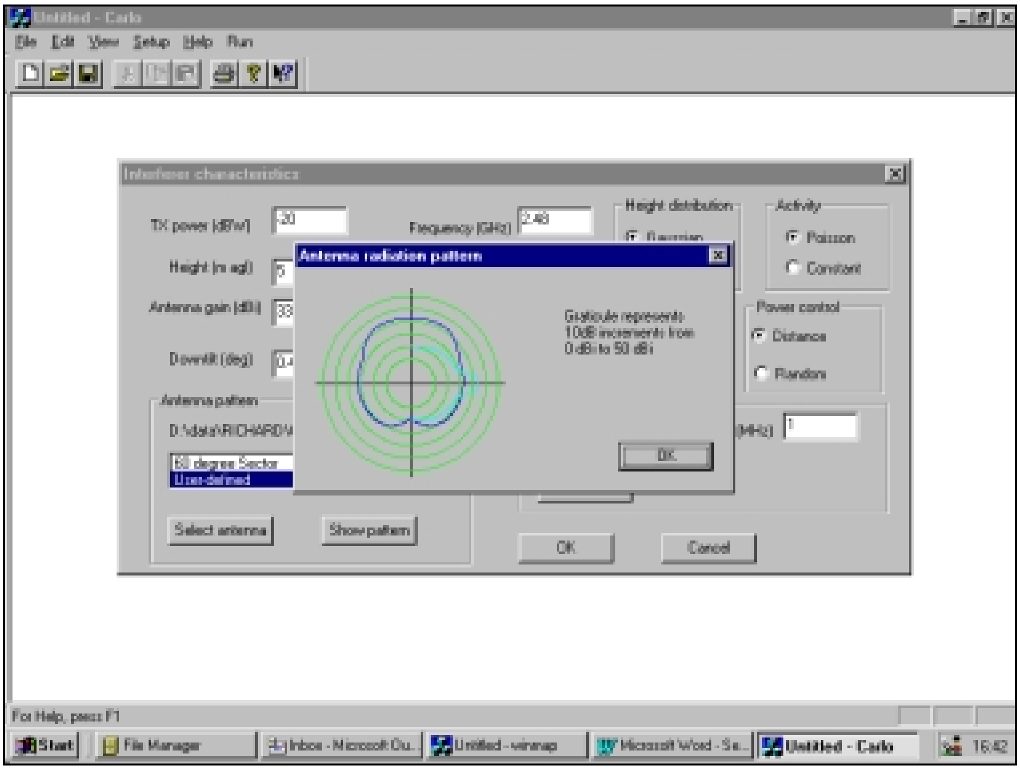


**Figure D.2: ASSET data entry screen**

For each of the 1,000 trials in a simulation run, the interference from the transmitter population is aggregated at the victim receiver. The output of the model is in the form of a cumulative distribution function (CDF), indicating the probability of a typical receiver suffering interference for a particular scenario.

The cumulative interference level from multiple interferers is highly dependent on how many interferers are likely to have a line of sight propagation path to the victim receiver. In practice, the probability of a line of sight path diminishes rapidly at separation distances greater than the typical network cell size (this is a necessary condition for effective cellular planning). This is especially so where the interferer or victim is mounted at a low elevation relative to surrounding buildings or terrain (this is why the base station to base station scenario, where both interferer and victim are likely to be highly elevated, is considered to be the absolute worst case).

However, whilst most potential interferers are unlikely to have a line of sight path to the victim, in a typical scenario it is likely that more than one interferer could contribute to the total interference received by the victim. This is particularly the case for PMP base stations with highly elevated wide beam antennas.

Monte Carlo simulations of a variety of interferer / victim scenarios have been carried out for each interferer / victim combination. The statistical analyses have been carried out at 28 GHz, since cumulative interference levels are likely to be lower at 42 GHz, reflecting higher levels of free space, atmospheric and clutter attenuation.