Project	**IEEE 802.16 Broadband Wireless Access Working Group <http://ieee802.org/16>**
Title	**Adjacent Frequency Block Co-existence**
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Re:	Contribution to the discussion in the 802.16.2 working group resulting from an Action item taken on during Session 9 in Denver.
Abstract	Provides an evaluation of frequency guard band requirements to address co-existence between BWA operators in the same geographic area and adjacent frequency blocks. Proposals for the Recommended Practice document are included.
Purpose	To provide input for clause 8.10.1 of the draft Recommended Practice.
Notice	
Release	
Patent Policy and Procedures	

Adjacent Frequency Block Co-existence

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Introduction

In this coexistence scenario between BWA operators assigned adjacent frequency blocks in the same geographic area, significant spatial separation between interferer and victim cannot be assumed and co-existence relies upon:

a) frequency separation between interferer and victim
b) frequency discrimination of the transmitter and receiver.

Some parameters values 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. These and additional parameter values for the purposes of the simulation work are detailed in Annex A.

The coexistence situation can be improved in cases where specific sub-bands can be defined for uplink and downlink transmitters however with the technology options available for BWA this is not always possible. Therefore this paper considers appropriate frequency separation requirements based on victims and interfering sources in immediately adjacent frequency blocks.

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 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).

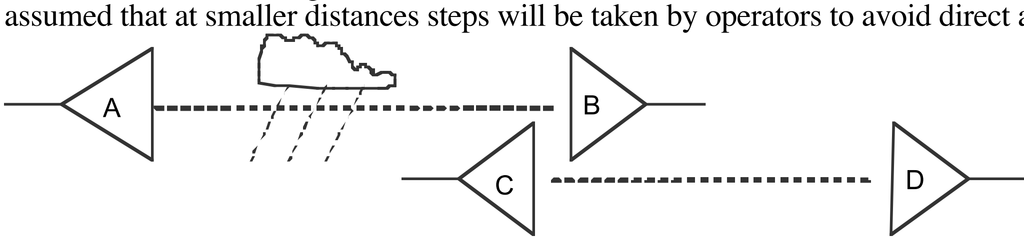

Figure 1: Hypothetical worst case co-located interference scenario

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:

$$P_{rx} = 11.5 - FSPL + G_{rx}$$
$$= 13 - 95 + 33 \quad (f = 27.5 \text{ GHz})$$
$$\mathbf{= -49 \text{ dBW / MHz}}$$

This exceeds the wanted signal level from D by 71 dB and the notional interference limit of kTBF-10dB (-146dBW/MHz) 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 in an adjacent channel 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 standards[1] 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.

Spectrum Masks

Figure 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.

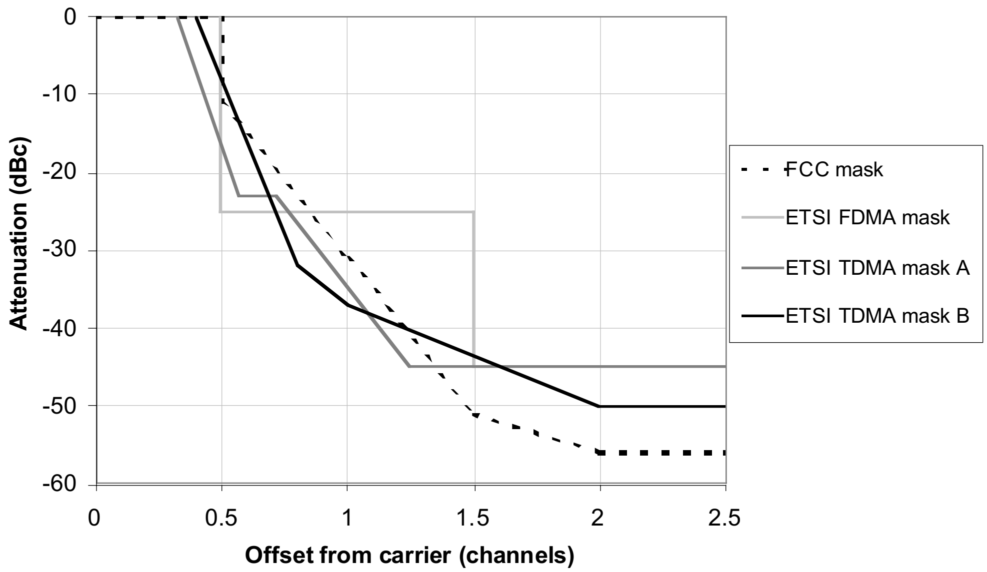

Figure 2: Transmitter spectrum masks defined in EN 301 213

The above masks imply that there is no further improvement in the filter rejection below the mask floor indicated, regardless of the carrier spacing.

Net Filter Discrimination

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 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.

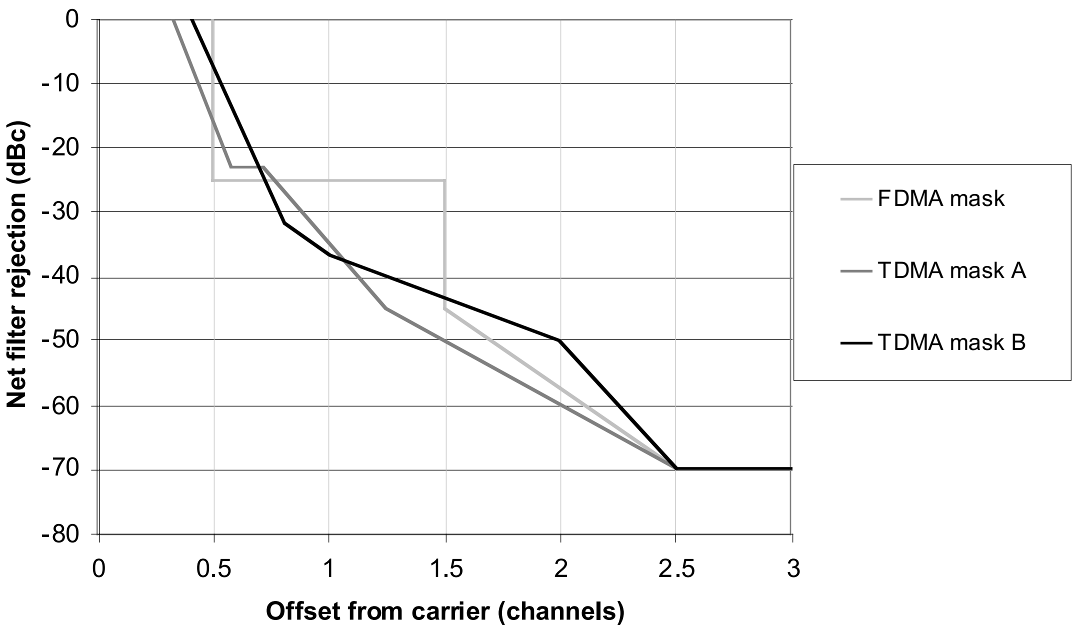

Figure 3: NFR curves based on EN 301 213 spectrum masks and –70 dBc floor

Co-channel interference into a victim

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.

Through examination of the ETSI performance parameters for co and adjacent channel operation and calculations of separation distances against interference levels for a range of frequency separations it can be shown that the worst case is that of adjacent channel emissions falling co-channel in the victim.

Worst case scenario

Figure 4 shows the result of worst case separation distance calculations for a range of frequency seperations for an FDMA interferer and a FDMA victim. (FDMA system parameters were used as they appear to exhibit the worst case spectrum mask and NFR curve.).

Figure 4 suggests that in order to meet the co-channel interference criterion defined in EN301-213, between directly aligned subscriber stations at all times, separation distances of around 1km would be needed even with frequency separations equivalent to 3 times the channel spacing. (In fact the response at greater separations is similar as the –70dBc floor has been reached).

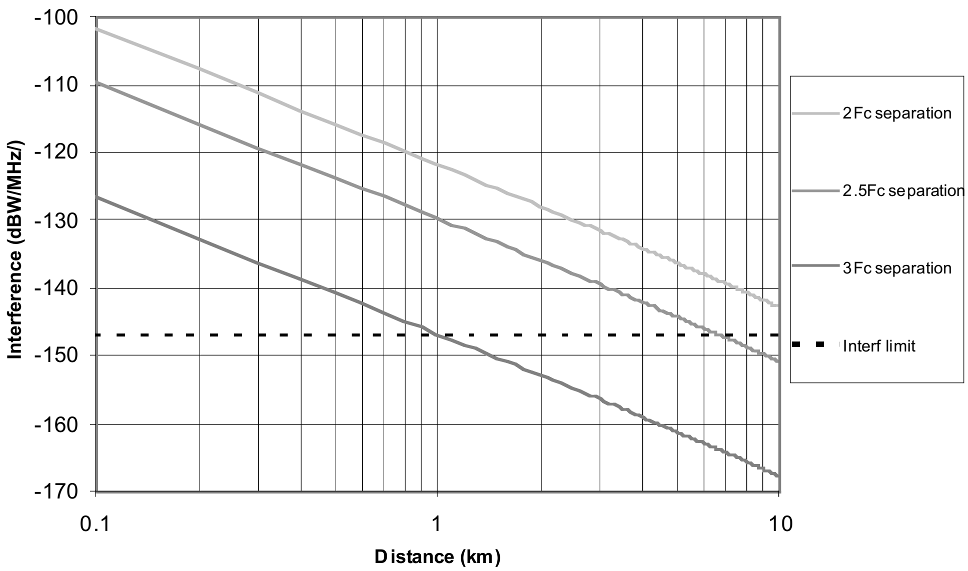

Figure 4: Co-channel interference between an FDMA interferer and an FDMA victim, as a function of separation distance & carrier frequency offset

However, it has to be recognised that the probability of the worst case scenario arising is limited (see other work on Interference Scenario Occurrence Probability – ISOP and Interfered Area – IA) in practice and the guard band requirement should therefore take account of the statistical spread of interference in a typical co-existence scenario.

Statistical Analysis

Figure 5 presents interference CDFs for interference between various combinations of interferer and victim. The interferers were randomly distributed around the victim station for every trial. An exclusion distance between the victim and interferer of 50m was chosen (in order to avoid possibility of co-siting the two). The victim is pointing in the same direction throughout the simulation in order to randomise the directivity between victim and potential interferers.

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

PMP Base station is assumed to be transmitting at full power throughout the modelling ATPC is deployed for both PMP and mesh subscribers to counteract rain fading and different distances. 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 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 0.01 per km^2 for PMP networks and 0.45 per km^2 for high density mesh networks.

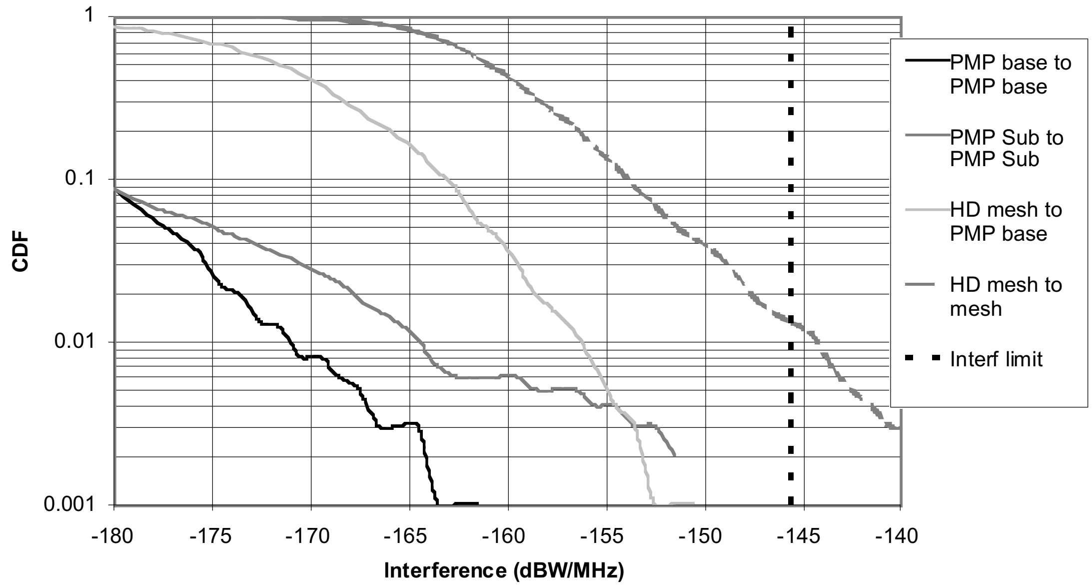

Figure 5: Interference CDFs between networks using identical channel spacings

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.

Co-ordination between systems using different channel spacings

The work above 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 6, 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.

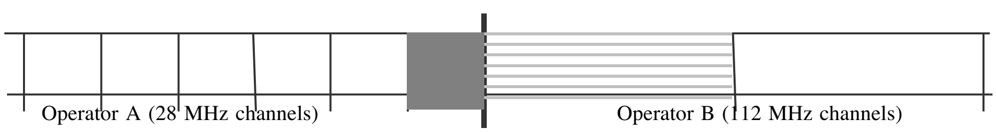

Figure 6: Use of different channel spacings in adjacent bands

Statistical Analysis

As outlined above, 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 3. The following plots show interference CDFs for guard bands **per operator** of one channel spacing and half the channel spacing.

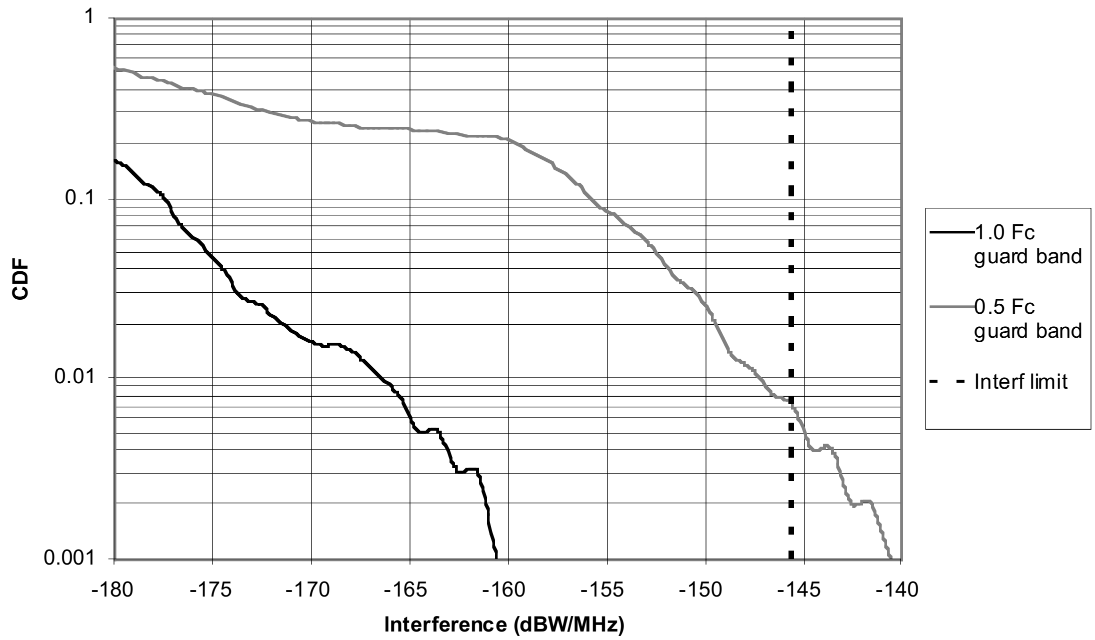

Figure 7: Interference between PMP base stations (interferer density 0.009 per km^2)

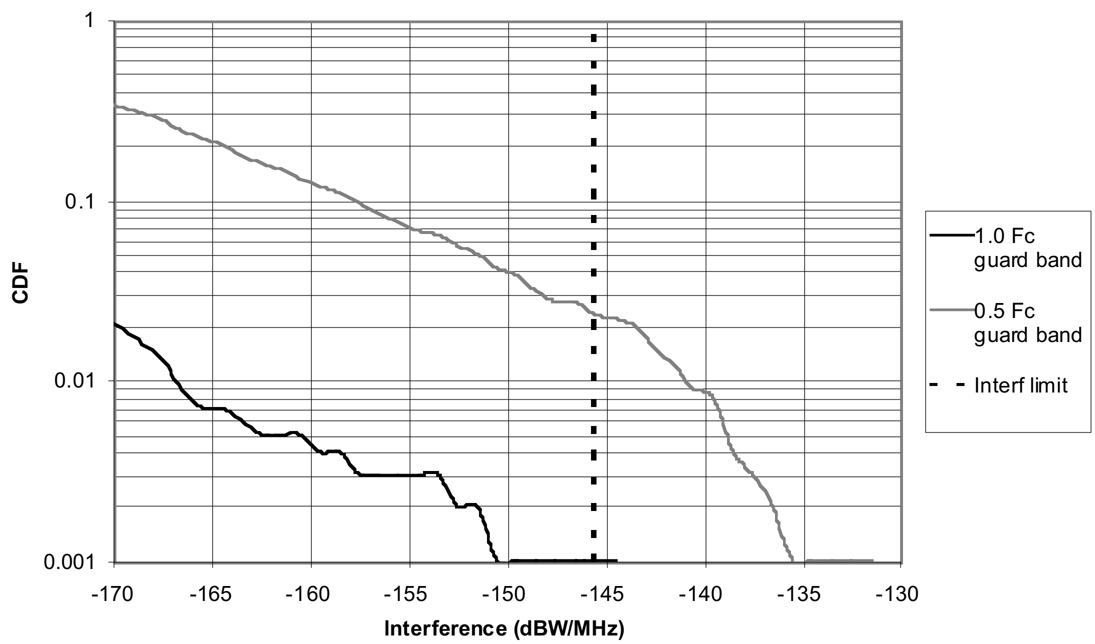

Figure 8: Interference between PMP subscribers (interferer density 0.009 per km^2)

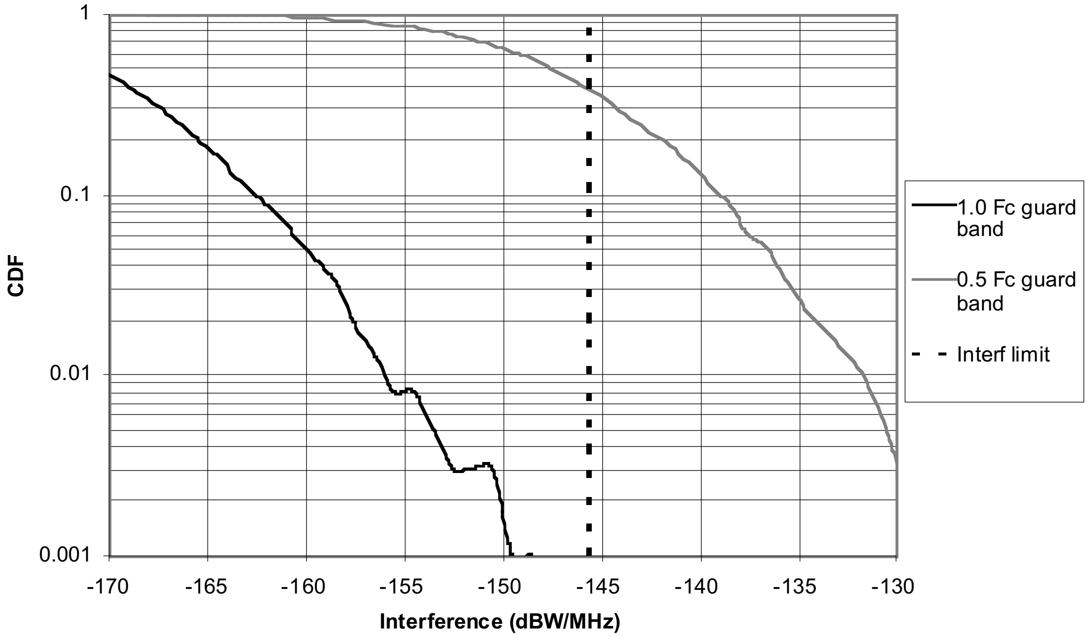

Figure 9: Interference between high density mesh network and PMP base station (interferer density 0.45 per km^2)

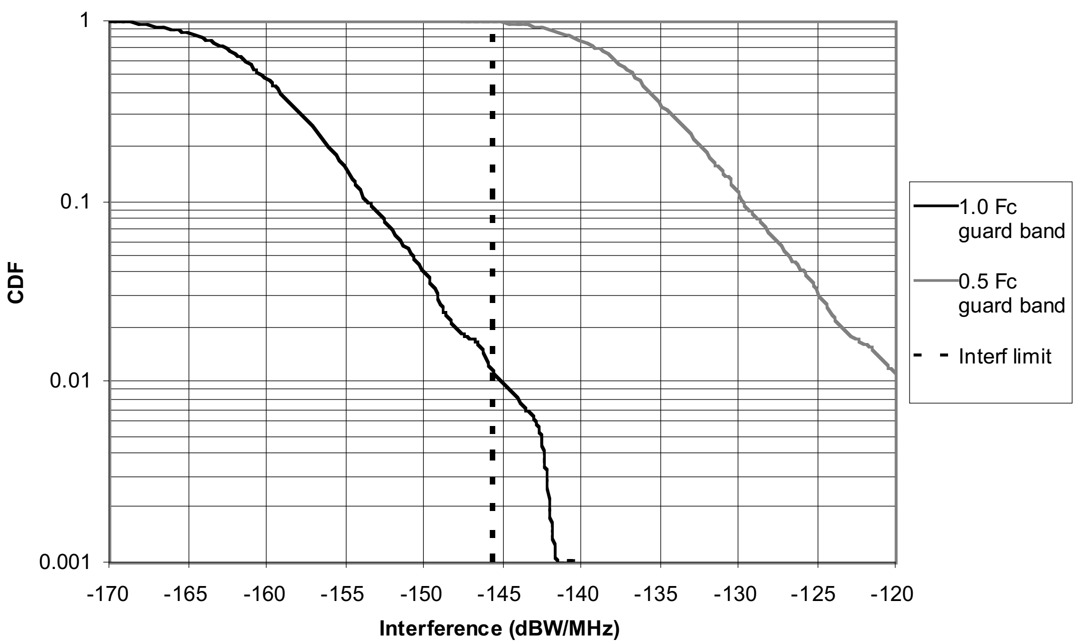

Figure 10: Interference between high density mesh networks (interferer density 0.45 per km^2)

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.

Text Proposals for the draft Recommended Practice Document

With reference to and extracts from clause 8.1 of the draft IEEE 802.16.2-00/01r9b:

Overlapping Area Case

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

1. frequency separation between interferer and victim
2. frequency discrimination of the transmitter and receiver.

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

Hub to hub interference (CS – CS)

In PMP systems, this type of interference is evaluated by use of a simulation program. It is clear that an interfering CS could be relatively close to a victim CS but the level of interference depends on the relative locations of the CS's of the two systems (which affects the antenna pointing direction). Analysis shows that a single guard channel between systems will in general be a good guideline for uncoordinated deployment when the systems employ similar channel spacings. Where channel spacings are considerably different then one equivalent guard channel should be implemented at the edge of each operators block.

Sub to hub interference (TS – CS)

In PMP systems, this type of interference is evaluated by use of a simulation program. It is clear that an interfering TS could be relatively close to a victim CS but the level of interference depends on the relative locations of the hubs of the two systems (which affects the antenna pointing direction) on the use of ATPC and on possible differential rain fading. This case is analyzed in [xx] and shows that a single guard channel between systems will in general be a good guideline for uncoordinated deployment. Where channel spacings are considerably different then one equivalent guard channel should be implemented at the edge of each operators block.

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

Subscriber to subscriber, same area case (TS –TS)

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

An analysis of this case can be found in [xx] for the PMP case and in [xx] for the mesh-PMP case. This case is analyzed in [yy] and shows that a single guard channel between systems will in general be a good guideline for uncoordinated deployment. Where channel spacings are considerably different then one equivalent guard channel should be implemented at the edge of each operators block.

Annex 1 [update RA annex]

Assumed System Parameter Values

For the purposes of the Monte Carlo testing, the following system,deployment and propagation parameter values were assumed:

Assumed parameters for interference analysis:

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

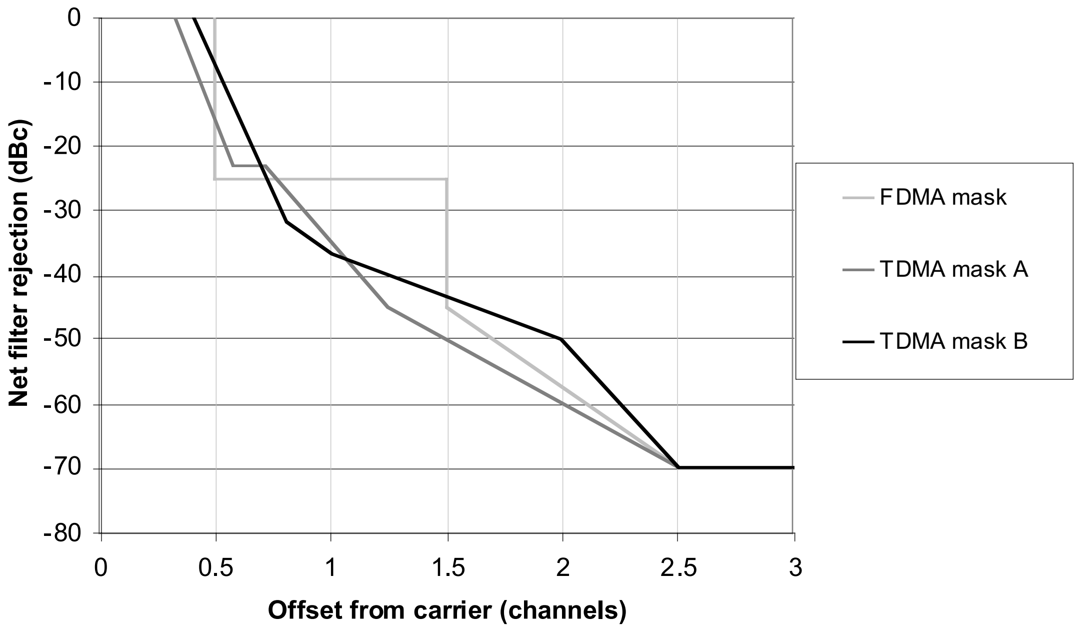

Figure [Annex x 1]: NFR curves based on EN 301 213 spectrum masks and –70 dBc floor