Spectrum usage rights

Ofcom

Final Report - Case Studies

1721/TNR/FR2/1

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1 INTRODUCTION

1.1 Document Context

This document describes the case studies examined as part of the study into Spectrum Usage Rights by Aegis, Indepen and Transfinite. It should be read in conjunction with the Final Report which is available as a separate document.

These case studies should be considered within the wider framework proposed for Spectrum Management Rights (SMRs) and Spectrum Usage Rights (SURs) as described in the main document.

1.2 Structure of Document

This document contains the following sections:

Section 2: Background. This section describes the regulatory framework within which the case studies were defined, the objectives, and the questions to be addressed together with a summary of the case studies examined.

Section 3: Overview of SMR Case Studies. This section describes in overview the case studies relating to SMR including conclusions reached and issues raised. The details of the relevant case studies can be found in Annexes A, B, C and D;

Section 4: Overview of the SUR Case Studies. This section describes in overview the case studies relating to SUR including conclusions reached and issues raised. The details of the relevant case studies can be found in Annexes E and F.

Section 5: Conclusions. This section summarises the results of the Case Studies.

2 BACKGROUND

2.1 Regulatory Framework

It is not feasible to isolate the behaviour of individual radio communication systems due to the fundamental nature of radio propagation. Radio waves spread out geographically and leak across frequency boundaries, and this can result in interference which could seriously degrade system performance.

Section 3 of the main document identified a range of technical issues relating to this interference that would need to be addressed, such as in-band and out-of-band (OOB) paths and the effect of aggregation and apportionment.

A key objective of regulatory bodies such as Ofcom is to manage the radio spectrum in an efficient manner and in particular avoid harmful interference. Therefore the regulatory framework for spectrum users must include controls on how systems operate, through the definition of rights and responsibilities.

Section 4 of the main document proposed a regulatory framework that would permit flexibility while retaining sufficient control on interference issues. This structure splits rights into two levels:

- Spectrum Management Rights (SMRs) – relating to control of a block of spectrum extending in (geography, frequency, time);
- Spectrum Usage Rights (SURs) – defining the right to transmit or receive at specific locations or areas with specific characteristics.

Typically SURs are issued by the relevant SMR owner: these could be for the SMR owners use (for example by an operator) or for another’s use (when the SMR is operating as the band manager). However in some bands it is expected that – e.g. for legacy reasons - the SURs would be issued and managed by Ofcom itself.

An example structure is shown in the figure below.

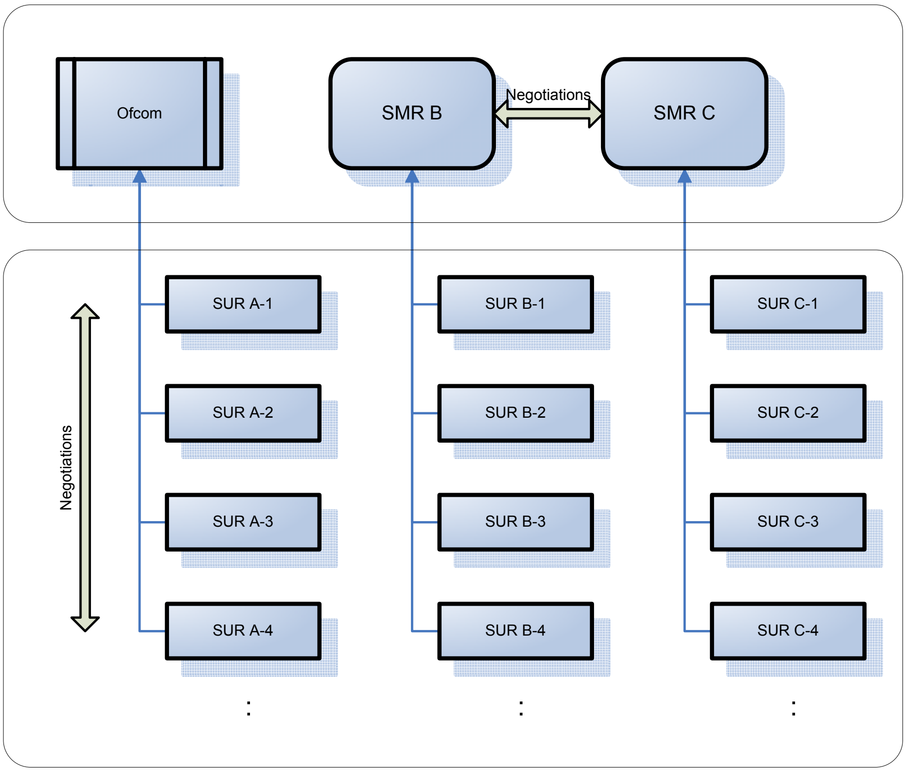

Figure 1: Regulatory Structure for Case Studies

This structure is not intended to be static, but to be able to adjust to change (such as economic or technical) in a way that also manages interference. Some of these changes – such as trading of SMR – do not in themselves raise interference issues and so are not discussed further.

It should be noted that SMRs per se do not cause or suffer interference – it is only the SURs which relates to usage of the spectrum. There is therefore the potential to cause or suffer interference when one of the following two events occurs:

1) An SMR owner issues or modifies the SUR within its responsibility. This will be subject to a defined process to manage interference;

2) An SUR owner changes their system characteristics. This will be subject to the constraints that its parameters remain within the envelope for that band and interference into neighbouring SURs is below the agreed thresholds;

For the latter case, the rights of an SUR owner will be subject to the contractual agreement with the manager of their band. These rights could be limited (for example with a Spectrum Management Organisation or SMO) but where the manager is Ofcom, it could permit such Change of Use (CoU).

Note that in both cases above there is the option for negotiation. For example the SMR owner can negotiate with its neighbours to change the process by which it issues or modifies SURs. Similarly the SUR owner can negotiate with its neighbouring SURs to changes the thresholds for interference.

2.2 Objectives and Questions

The case studies were undertaken in parallel with development of the overall framework. Their objective was to:

- Improve understanding of the issues relating to interference management within a flexible framework;
- Analyse the implications of particular sets of management or usage rights;
- Address some of the issues raised by respondents to the Spectrum Framework Review (SFR);
- Determine the relative strengths of proposals under range of scenarios (e.g. bands and types of system);
- Provide feedback into the development of the overall regulatory framework;
- Build confidence in the approaches proposed.

Question addressed included:

1. How can spectrum management and usage rights be defined to control interference within a flexible regulatory framework?
2. What alternative processes could be considered by which an SMR introduces SURs?
3. How does the process for one SMR to introduce SURs protect other SMRs from interference?
4. What are the implications in terms of risk and constraints in the process by which an SMR introduces SURs?
5. Is it feasible for Ofcom to give SUR owners the right to change their parameters and yet give assurances to other SURs they will be protected from interference?

2.3 Criteria to Assess Parameters

A wide range of possible parameter sets could be used to define spectrum rights. The following criteria are used as a set of checks that the parameters selected are suitable:

1. **Transparent**: it should be easily apparent what the licence holder is permitted to do and what protection from interference they can expect;
2. **Technologically neutral**: the parameters selected should be those necessary to ensure efficient management of the radio spectrum including interference issues without requiring identification of particular services;
3. **Complete and consistent**: there should as far as possible be little or no ambiguity and the data set should not contain inconsistencies;
4. **Measurable**: to ensure that compliance with licence terms can be verified.

2.4 Case Studies Considered

In order to test the framework and proposals with sufficient vigour the consortium ensured that the range of scenarios considered covered:

- Analysis at both the SMR and SUR level within the framework;
- Examples of both public and private management and use of spectrum;
- Inclusion of both in-band and out-of-band interference paths;

As there is significant differences between the rights at the SMR level and the SUR level these were considered separately.

The case studies included examinations with examples of the following types of service:

- Point to Point (P-P) Fixed Service (FS)
- Broadcasting - Digital Audio Broadcasting (DAB)
- Business Radio (BR)
- 2G Mobile
- 3G Mobile including both Frequency Division Duplex (FDD) and Time Division Duplex (TDD)
- Radar

2.4.1 SMR Case Studies

The SMR case studies are described section 3 in overview with detail in Annexes A, B, C, and D. These included:

1. In-band sharing between public user of spectrum (radar) and a mobile operator;
2. In-band sharing between two operators providing mobile services;
3. Out-of-band sharing between two operators who initially are both providing mobile services.

2.4.2 SUR Case Studies

The SUR case studies are described section 4 in overview with detail in Annexes E and F. These included

1. In-band change of use from BR to DAB;
2. Out-of-band change of use from BR to DAB;
3. In-band change of use from point to point FS link changed to low power mobile network.

2.5 Selection of Bands, Services and Parameters

Important Note:

The case study scenarios were devised based upon general principles and not necessarily on any known planned or actual usage within the bands selected.

The parameters used were selected for the purposes of the case studies and are not necessarily based upon any known real or planned networks.

3 SMR CASE STUDIES

3.1 Introduction

The objective of the case studies described in this section was to analyse the impact of various alternative technical approaches that could be used to manage interference between SMRs.

The case studies were split into two categories:

1) Scenarios relating to in-band (IB) compatibility between SMRs;

2) Scenarios relating to out-of-band (OOB) compatibility between SMRs.

3.2 In-band SMR Case Studies

Two cases studies were considered where a band was split geographically between two SMR owners. In both cases one of the SMRs was a mobile network: in the first case study the other SMR was a radiolocation network (for example as would be used by the MoD or CAA) while the latter case study considered another mobile network.

The in-band case studies focused on the management of interference due to the deployment of SURs – in this case new base stations by a mobile operator. Three mechanisms were considered to manage the deployment of new SURs by the mobile operator, namely:

1. Deployment of new base stations is permitted anywhere within a geographic boundary as long as the base station EIRP is no more than a specified level;
2. Deployment of new base stations is permitted as long as each are approved by a technical coordination tool;
3. Deployment of new base stations is permitted as long as the aggregate power flux density (PFD) from all base stations at a defined boundary is no more than a specified level.

The figure below shows the UK divided geographically between radars in Scotland and a mobile network within England.

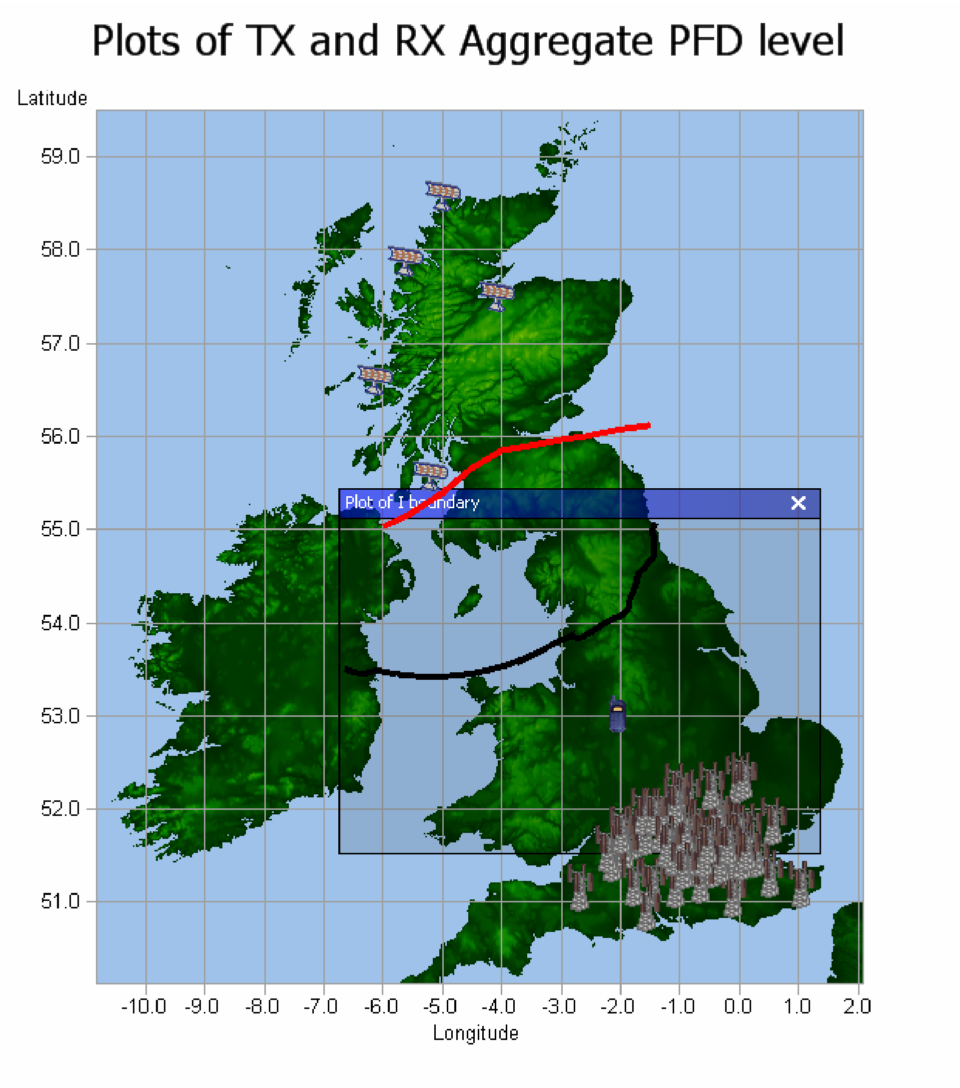

Figure 2: SMR In-band Case Study

Interference analysis was undertaken to determine the impact of the assumptions made. Details of the analysis can be found in Annex A and B. The following sections summaries the conclusion.

3.2.1 Approach 1: Deployment boundary plus EIRP limits

- This approach is relatively transparent in its definitions and hence straightforward to enforce;
- The calculation of boundary to protect the various systems required assumptions about the aggregation effect from large numbers of transmitters which could be wrong;
- The calculation of boundary to protect from interference from the radar sites requires parameters that might not be available for disclosure.
- For some auctions the boundaries will be fixed by other constraints – for example regions – and hence this approach would not ensure protection of

systems against interference across the boundary unless there was a clearly defined quiet zone between the two licences;

- This approach might be more applicable to scenarios where there is the ability to choose where the boundary should be in such a way as to control interference.

3.2.2 Approach 2: Technical Coordination of Deployments

- This approach can result in high technical spectrum efficiency;
- It requires close co-operation between the parties involved, which might be difficult for scenarios involving bodies such as the MoD.
- One solution would be for the MoD to act as Band Manager issuing SURs to the mobile operator for each BS.
- These activities could be facilitated or managed by a trusted third party;
- This approach is likely to introduce a degree of first come first serve.

3.2.3 Approach 3: Aggregate PFD on or beyond Boundary

- This approach gives the operator significant flexibilities in deploying their systems as long as they ensure the aggregate PFD they produce remains within licence conditions.
- The receive aggregate PFD gives a good indication of spectrum quality;
- In both cases the PFD level would have to be assumed to be constant beyond the boundary: this is a necessary but conservative assumption which can reduce technical spectrum efficiency;
- It is important that the PFD level has an associated percentage of time;
- The boundary can be moved to hide specific details about a system (transmitter or receiver characteristics) and to increase operational flexibility but at the cost of technical spectrum efficiency;
- The position of the boundary can reflect the various needs and requirements of stakeholders, and represent a good starting point for negotiations.

3.2.4 Summary

This analysis above considered three methods to manage in-band interference:

a) Maximum EIRP plus Deployment Boundary

b) Maximum EIRP plus Technical Coordination

c) Maximum EIRP plus Aggregate PFD on Boundary

All methods considered could be used to manage in-band interference between geographically separated radio systems and each approach has its advantages and disadvantages.

3.3 Out-of-band SMR Case Studies

The OOB case studies used as the baseline a scenario where there were two 3G networks in the same geographical area operating in adjacent bands and a number of changes to the status quo were considered, namely:

1) Introduction of new base station using existing technology;
2) Significant increase in the number and hence density of base station deployed;
3) Introduction of adaptive antennas resulting in increase in user densities;
4) Change of carrier shape (e.g. 2G to 3G or 3G to 4G);
5) Change in operation from FDD to TDD with reverse band working;
6) Introduction and operation of fixed user terminal with higher gain antennas;
7) Change in service to higher power system providing more broadcast like services;
8) Change of technology to maximise throughput by transmitting at maximum EIRP permitted continuously (e.g. use of adaptive coding)

For the scenarios above various technical mechanisms to manage OOB interference was considered, including:

- Approach 1: Use of EIRP Mask. An operator can deploy a base station at any location within their licensed area as long as the levels of out-of-band emissions into adjacent bands are within the levels defined in the SMR. A number of sub-approaches were considered including low or high out-of-band EIRP levels.
- Approach 2: OOB PFD Mask. An operator can deploy a base station at any location within their licensed area as long as the aggregate PFD received in adjacent bands does not exceed specified levels for defined percentages of locations and times. More information on the OOB PFD concept and an example derivation can be found in Annex D.2.
- Approach 3: Technical Coordination. An operator can deploy a base station at any location within their licensed area as long as interference analysis indicates it would not exceed interference thresholds of SURs of adjacent operators.
- Approach 4: Technical Standard. An operator can deploy a base station at any location within their licensed area as long it meets an agreed defined standard.

The results of analysis of these methods are described in summary below with more information in the Annexes. Due to the complexity of the FDD to TDD case it was analysed in detail as described in Annex C. The analysis of the other scenarios is described in Annex D.

3.3.1 Approach 1: Use of EIRP Mask

Defining the envelope of SUR parameters – such as maximum in-band EIRP, EIRP mask and antenna height – has the advantage of simplicity and technology neutrality. The implications of this approach vary depending upon the level of the EIRP mask selected that must be met, as described in the following sub-sections.

3.3.1.1 Approach 1a: High EIRP Mask

One approach to define the mask is to take one typically usage of a band and determines the usable OOB EIRP mask for that service. Any application that has a carrier that meets that level is then permitted to operate, regardless of standard or technology.

However this approach could permit some changes that could introduce the risk of interference. For example it could permit networks to deploy with high densities and constantly operating at maximum EIRP. Analysis using the case study scenario of adjacent mobile operators suggests that this approach can lead to significant degradation in system performance.

3.3.1.2 Approach 1b: Low EIRP Mask

An alternative approach is to define the OOB EIRP mask to be sufficiently tight that interference would only occur over extremely short distances. Typically this distance is one for which there is user control – for example for mobiles it could be around a metre while for base stations it could be 10 metres. From a receiver interference threshold, typical noise figures, and free attenuation for this short distance, the maximum EIRP mask levels can be derived.

This approach has the advantage that there are minimal risks of interference. The owner of each block of spectrum can still operate but typically must either introduce filtering and/or a guard band. However because other elements of the system operation are not included (for example use of power control or highly directional antennas) it could be overly cautions.

For example it would not permit two mobile operators to introduce WCDMA carriers in adjacent 5 MHz channels without additional filtering, even though detailed modelling and practical experience suggests this is technically achievable. Therefore this approach could initially lead to lower technically spectrum efficiency.

It does however represent a technically robust starting point for negotiations between SMR owners – who could for example agree to raise the EIRP mask if they both employ equipment that meets the 3GPP specification.

3.3.1.3 Approach 1c: EIRP Mask plus Minimum Distance

This approach is based upon allowing any change of use as long as the interference level in adjacent bands at the boundary of lands in the control of the SMR owner (either via ownership or leased rights) is below a given level. By increasing this controlled zone the SMR owner would be permitted to operate at higher powers.

As noted above, use of a technique based upon EIRP plus minimum distance tended to give overly conservative results for scenarios where there could be significant variations in locations and powers.

Therefore this approach could be overly pessimistic unless the interference would occur only over very short distances. In addition for mobile applications there is minimal control over separation distances, and so this approach might be more applicable to scenarios involving interference between fixed transmitters.

3.3.1.4 Approach 1d: Variable EIRP Mask

It was noted above that the low EIRP mask has the benefit that it is technically robust and provides good protection from interference. However it could be restrictive – resulting in lower technical spectrum efficiency.

One approach to improve efficiency without introducing excessive risk of interference is to permit higher levels of OOB interference in urban areas where cell sizes are typically smaller and hence there could be increased margin for interference. The EIRP mask could be calculated with two noise figures – one for urban areas and another for rural area.

However this might be insufficient a relaxation to permit the adjacent band 3G network example while introducing additional complexity and hence reduced transparency.

3.3.1.5 Summary

Use of EIRP mask has the benefit of simplicity, transparency and technological neutrality. However as noted above, selection of the level to use introduces one of two risks:

1) Low EIRP mask: potential risk of lower technical spectrum efficiency unless negotiations occur;
2) High EIRP mask: potential risk of interference unless negotiations occur;

Other approaches were considered – such as use of more than one EIRP mask or ability to change the minimum distance. However neither of these removed both of the two risks identified above.

3.3.2 Approach 2: OOB PFD Mask

This approach would give a good idea of the level of interference that operators in adjacent bands could experience. It also would give operators a good idea about how they could deploy their network flexibly without causing interference.

It would not be possible to dramatically increase density of either BS or MS without reduction of EIRP as that would result in linear increase in percentage of locations interfered. Similarly it would not be possible to switch off power control without either reducing EIRPs or entering into negotiations.

However difficulties were noted in calculating suitable values which initial study suggested could vary significantly depending upon deployment assumptions (e.g. whether macro / micro / pico). Assuming that the same values are to applied to all locations within the licensed area might lead to interference problems. Alternatively the value of the OOB PFD levels could vary by location with different values for urban, suburban and rural environments.

It was noted that computation of suitable values requires detailed understanding of the system being modelled. Such complex analysis leads to complexity and a loss of transparency, and results that are reliant upon the assumptions used and in particular the reference system used.

In addition there would be no information about interference at actual locations – only the probability that a location experiences interference.

3.3.3 Approach 3: Technical Coordination

Technical coordination of each individual deployment can be achieved using suitable interference analysis tools and associated databases. This would require access to databases of SURs containing detail to permit interference analysis, including the Indicative Interference Level (IIL)[1] and receiver characteristics of each station.

This approach could in theory permit all changes above i.e. 1 – 8 should the SMR owner undertake checks with suitable analysis software. It is noted that a similar approach is available within the Australian and New Zealand regulatory frameworks.

There are likely to be locations with high levels of demand where there is competition between stakeholders for access to spectrum. One approach to resolve this which has been considered in similar circumstances is to give priority to the first to register based upon the principle of first come first serve.

3.3.4 Approach 4: Use of specific technology and/or standard

If SMR owners can only deploy SUR that are compatible with a specific standard, and when that standard is defined in detail, then there will be a good understanding of the OOB interference it will generate. The constraint of only using a specific standard typically limits the interference potential.

This approach will restrict the flexibility for SMR owners such that changes 3 - 8 above would not be permitted. It would be feasible to increase the density of BS and mobiles (changes 2 & 3), but the nature of the standard would manage the OOB interference. Typically there would be high density of transmitters in urban areas where other operators expect increase noise and tend to use smaller cells.

This approach does not necessarily imply imposition of a specific standard by Ofcom as it could be the result of negotiations between adjacent SMR owners. The agreement to use a specific technology and/or standard is a way of quickly and simply describing a system to a relatively high level of detail.

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[1] The IIL gives an indication of interference into an individual SUR. Another metric, the Spectrum Quality Benchmark or SQB, gives information the interference environment at the SMR level.

3.3.5 Summary

It was found to be harder to manage out-of-band interference paths than in-band interference paths. Each approach has its advantages and disadvantages and areas of risk.

The table below compares each method.

Method to manage OOB interference	Transparency & Simplicity	Technology Neutrality	Completeness (ability to reduce risk)	Measurability	Technical Spectrum Efficiency	Flexibility (allowing changes)	Overall
1a. EIRP Mask (low level)	High	High	Medium	High	Medium	High	High
1b. EIRP Mask (high level)	High	High	Medium	High	Medium	High	High
1c. EIRP Mask + minimum distance	High	High	Medium	High	Medium	High	High
1d. EIRP Mask (low rural + high urban)	High	High	Medium	High	Medium	High	High
2. OOB PFD	Low	High	High	Medium	High	High	Medium
3. Technical Coordination	Medium	High	High	High	High	High	High
4. Specific Technology or Standard	High	Low	High	High	High	Low	Low

Table 1: Comparison of Methods to Manage OOB Interference

4 SUR CASE STUDIES

4.1 Introduction

The objective of these case studies was to show how the definition of SURs would be applied to actual radio communications systems and how the process would ensure that existing user's rights are protected.

The change of uses proposed were selected taking into account their potential economically viability. In addition, the technologies in all cases are sufficiently well defined to allow deployment to be foreseen and its parameters to be modelled.

In this section we describe the following Change of Use (CoU) scenarios relating to SURs:

1. Aggregation of BR Channels to DAB;
2. FS link changed to low power mobile network.

The following study methodology was applied:

1) Definition of scenarios;
2) Identification of system parameters from existing sources including TFACs, IRs, ETSI standards, ECC Reports and Recommendations, ITU-R Recommendations etc;
3) Definition of a consistent "AsIs" set of licences (i.e. provide the required service without exceeding interference thresholds);
4) Definition of a desired "ToBe" licence which would provide the required service level;
5) Mapping of system parameters to technology neutral spectrum usage rights;
6) Interference analysis using standard modelling techniques: where appropriate and applicable this used the Algorithm defined for the Generic Radio Modelling Tool for Spectrum Trading[2].
7) Analysis of potential for change of use to cause or suffer levels of interference above relevant Indicate Interference Level (IIL).
8) Analysis of process by which change of use would be approved or rejected including interaction with other stakeholders.

In some cases a degree of simplification was done to complete the interference analysis in the timescales required by this study.

[2] Being developed for Ofcom under a separate contract.

4.2 Measure of Interference

Compatibility measures can be defined in a number of ways – from complex (such as C/N+I and C/I) to more basic (such as I/N or interference in receiver bandwidth). A decision was therefore required as to what measure of spectrum quality should be used, taking into account:

- the need for technology neutrality;
- the need to be able to used to assess compatibility between all types of radio systems;
- the need to assess the quality of spectrum from a radio users perspective;
- the ability to be a measure than can be calculated in interference simulations;
- the need to be computable within reasonable timescales.

It was decided that a suitable format of the technology neutral interference threshold would be:

> *Interference at the receiver should not exceed X dBW for more than Y% of time [at no more than Z% of locations].*

This threshold is called the Indicative Interference Level or IIL. As it is measured at the reference receiver a bandwidth is implicitly specified via the receiver's RX mask which should be used in the interference calculation. By using this and the corresponding EIRP mask on the transmitter, the net filter discrimination can be included in the interference calculation.

4.3 Aggregation of BR Channels into DAB

4.3.1 Description of Scenario

The baseline for the scenario was the 450 MHz band populated with a number of wide area Business Radio (BR) networks. These provide voice communication services to private organisation, for example taxi or bus companies. The networks will have been planned so that they can operate using the parameters in their licences without causing or suffering interference from other licensed users.

An operator purchases a number of BR licences in the London area with contiguous spectrum and aggregates their narrow bandwidths to provide a wider band service, in this case Digital Audio Broadcasting or DAB. The locations of the various stations are shown in the figure below.

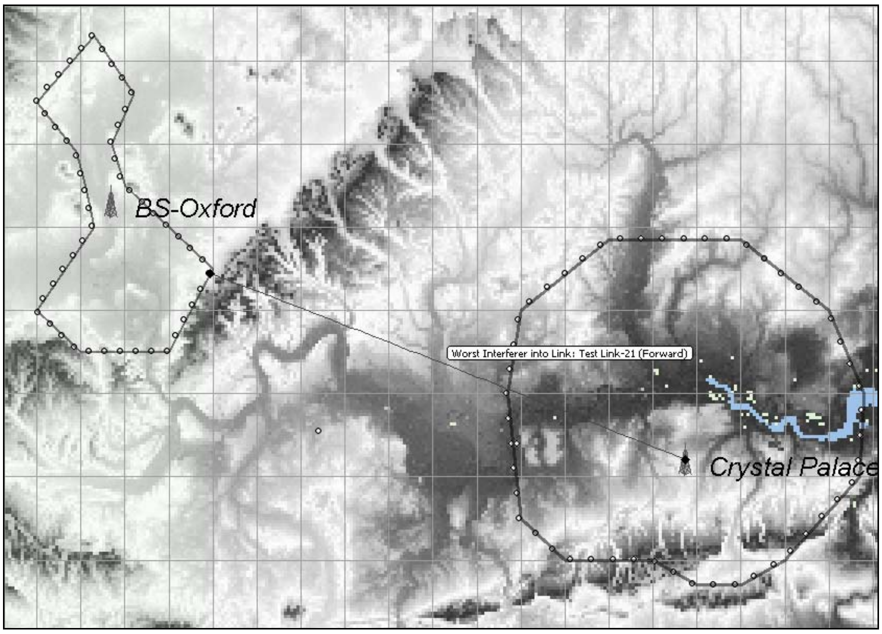

Figure 6: TDAB to BR Sharing Scenario

Rather than modelling all 62 bands, together with all BR networks in each, the following two typical networks were used to model in-band and out-of-band effects:

- BR typical co-located licence = Clapham
- BR typical co-frequency licence = Oxford

4.3.2 Results of Analysis

Despite using the same spectral power density as the BR network, the DAB transmitter was found to cause interference into the geographic adjacent BR networks. The principle reason for this was the increased transmitter height required to provide wide area DAB coverage.

The DAB network would still be able to operate, but only if it undertook at least one of the following steps:

1) Gain agreement from the BR radio operator that it would accept higher levels of interference;

2) Purchase additional BR licences over a wider area;

3) Reduce the transmit power and reduce the service provided either by increase coding and/or reduce modulation, resulting in reduced payload (i.e. lower data rate services or fewer channels) or accept lower QoS to users (i.e. reduced ability to serve indoor users without a fixed antenna);

4) Reduce the transmit power and accept the corresponding decrease in service area.

4.3.3 Issues Raised

The analysis undertaken for this case study raised the following issues:

- Directions to analyse CoU: Should interference analysis be calculated only from the modified system into others or also from other systems into the proposed CoU? For example if the current IIL is defined at the 0.1% of time level, what are the implications of requested a level of 0.01%?
- Apportionment of interference: How much of the aggregate interference allowance can be claimed by one individual system? How is the apportionment related to issues such as aggregation or splitting of licences, in-band vs. out-of-band interference?

These issues are discussed further below.

4.4 FS Link changed to Mobile Network

4.4.1 Description of Scenario

This scenario start with the “AsIs” scenario of the 1350 – 1375 MHz / 1492 – 1517 MHz bands populated with FS networks. For simplicity only two links are modelled in the London / Thames valley region, as in the figure below.

Figure 20: Scenario “AsIs” with two FS networks

The FS link operating closest to central London is assumed to request change of use to a mobile network. The frequency used in one FS direction used for the mobile uplink and the other for the mobile downlink.

This mobile network has then to ensure that the remaining FS link is protected i.e. interference is below the level in its IIL. The new scenario is shown in the figure below.

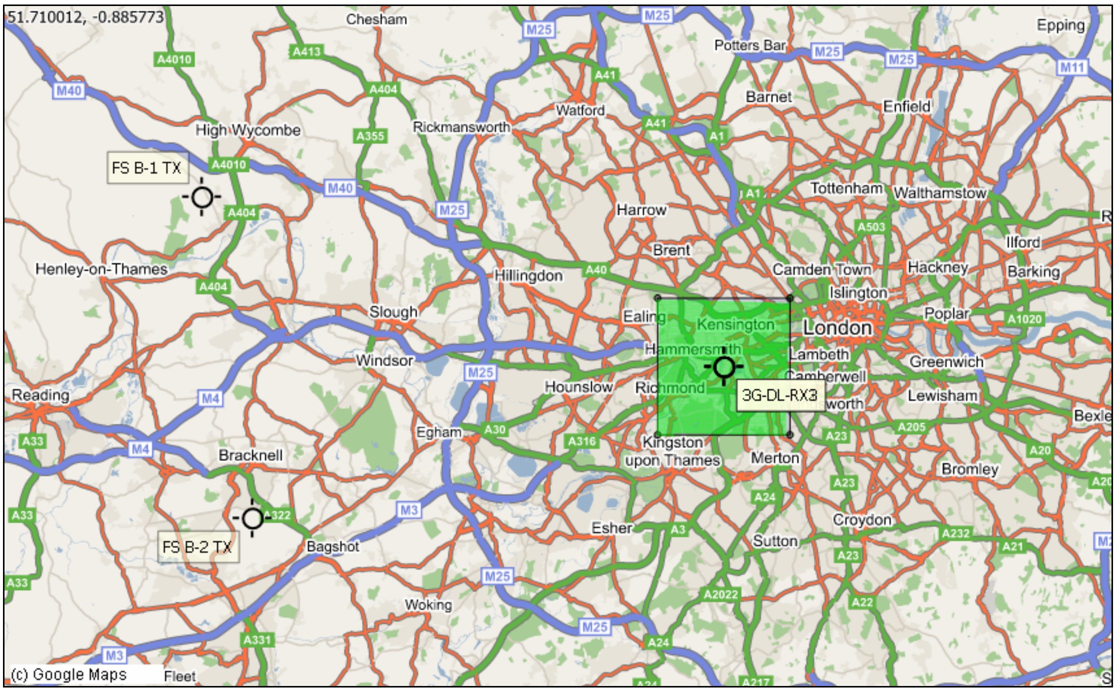

Figure 21: Scenario "ToBe" with FS network and mobile network

4.4.2 Results of Analysis

The table below summaries the results of the interference analysis:

Path	Results
From Mobile TX into FS RX	Pass
From Base Station TX into FS RX	Fail
From FS TX into Mobile RX	Pass
From FS TX into Base Station RX	Pass

Table 2: Results of Mobile – FS Case Study

The analysis suggested that the CoU would be not acceptable due to an excess of interference of about 30 dB on the path from the mobile BS into the FS receiver. The mobile operator would have available a number of options, including:

- Introduce measures to reduce interference (such as only use base station antennas that point away from the FS network);
- Locate Base Stations were there is additional protection (e.g. shielding) and gain agreement from the FS operator;
- Operate only low power base stations (e.g. around 0 dBW or 30 dBm);
- Purchase FS networks over a larger area;
- Seek agreement with the FS operators to compensate them for the increased interference.

4.4.3 Issues Raised

The analysis undertaken for this case study raised same issues as BR – DAB example (directions to analyse and apportionment) and also the following issues:

- Spectrum White Space. The analysis was only undertaken with a small number of systems. In practice with a congested band there would be a higher density of FS links and hence less margin for additional interference. In bands with only low density of systems currently deployed, can a change of use system take advantage of the spectrum white space?

These issues are discussed further in the following section.

4.5 Issues raised by SUR Case Studies

4.5.1 Directions to Analyse Change of Use

The standard issue when considering CoU is to ensure that the new licence configuration would not cause interference into the receivers of other licences. However there is benefit in undertaking additional checks to ensure the altered licence will not suffer interference from other licences, and not just for that licensee's operational benefit.

One of the fundamental requirements of any regulatory regime that permits liberalisation is that any CoU should not harm the rights of existing licensees to operate as defined in their licence. Therefore emission rights and receive IILs should remain consistent after a CoU

Should a licensee request a CoU to an extremely stringent IILs and it is approved by the regulator without checks, then there is the danger that it will not be consistent with the emission rights of other licences. Any CoU in any of these other licenses could be rejected for being inconsistent with the stringent IILs - even if they are identical to existing transmit levels.

Therefore if there are any changes to a licence's receive characteristics, including the IILs, there are significant benefits in ensuring the regulatory regime checks to ensure these are consistent with the existing emission rights of other licenses.

For example consider a band used for FS applications, in which all links have been well engineered to the 0.01% unavailability and there is currently little available margin. If there were no checks on the IIL proposed then the following sequence of events could occur:

1. Licence A proposes a CoU which has no significant impact on the interference into other licences (e.g. reduces its EIRP by 0.01 dB), but simultaneously requests a tighter IIL of 0.001% of the time.
2. As the interference produced by licence A is within the IILs of other licences the CoU is accepted;

3. Another licensee, B, then makes a similar request for CoU which would have no significant impact on interference into other licences (e.g. reduce its EIRP by 0.01 dB).
4. Examination of this proposed CoU is likely to show it would exceed the new tighter IIL of licence A of 0.001% of time and therefore the CoU would be rejected.

However this change should have been accepted as it is within the current emission rights.

The problem arose because the CoU by Licence A created an inconsistency between the transmit rights of one licence and the indicative interference levels of others.

This inconsistency could be trapped by the following procedure:

1. Licence A proposes a CoU which has no significant impact on the interference into other licences (e.g. reduces its EIRP by 0.01 dB), but simultaneously requests a tighter IIL of 0.001% of the time.
2. While the interference into other licences is found to be acceptable, the proposed tight IIL is found to be inconsistent with existing licence's transmit rights, and is therefore rejected
3. Licence A would have the option of submitting its minor changes with an IIL that would be acceptable (e.g. remaining at the 0.01% of time) and hence consistent with other licence's transmit rights.
4. Then when Licence B then undertook its minor change (e.g. reducing its EIRP by 0.01 dB) this would then pass as there would be consistency between all transmit rights and all requested IILs.

It is suggested that this latter approach is better, and a goal should be consistency between transmit rights and indicative interference levels.

4.5.2 Apportionment of Interference

In current bands such as those used by the Fixed Service or Business Radio there is typically homogeneity of systems characteristics. It is therefore relatively straight-forward to determine suitable single entry interference thresholds. In a generic framework with sharing between heterogeneous SURs defining suitable IILs becomes more complex.

For each receive system the key attribute of spectrum quality is the aggregate interference. However for assessments of proposed CoU the measure is the single entry interference that one SUR causes into another. It is therefore necessary to derive one from other using apportionment rules.

These rules must take account of:

- Differences in bandwidth between interferer and victim;

- Number of interfering entries to consider;
- Aggregation and splitting of SURs and corresponding interference allowances;
- Interference from both in-band and out-of band sources.

Examples of these cases are described in Annex E.3.2.

One possible approach is for the band manager, whether an SMO or Ofcom, to define an approach such as that given below. This would then give a transparent and simple methodology for assessment of CoU applications.

Example Apportionment Algorithm

Define the following general parameters:

I_{agg}: Aggregate interference at the receiver in dBW

F_{OOB}: Fraction of total interference allocated to out-of-band systems

N_{IB}: Number of in-band systems to consider

N_{OOB}: Number of out-of-band systems to consider

Initially these could be selected based upon expected or typical usage of the band.

The total interference is assumed to be firstly split between in-band and out-of-band sources using the F_{OOB} factor. Each contribution is then further split into a number of equal single entry interferers using the N_{IB} and N_{OOB} terms. Finally for the in-band case adjustments are made for differing bandwidths.

It is assumed that the interference has been calculated taking into account both the EIRP mask on the transmitter and the blocking mask at the receiver.

Hence for two systems with different bandwidths, where BW_v is that of the victim and BW_I is that for the interferer, the allowances would be:

If in-band then:

$$I_s = I_{agg} + 10\log_{10}(1 - F_{OOB}) - 10\log_{10}\left(N_{IB}\right) + A_{BW}$$

Where:

$$A_{BW} = \begin{cases} 0 & BW_I \geq BW_V \\ 10\log_{10}\left(\dfrac{BW_I}{BW_V}\right) & BW_I < BW_V \end{cases}$$

If out-of-band, then:

$$I_s = I_{agg} + 10\log_{10}(F_{OOB}) - 10\log_{10}\left(N_{OOB}\right)$$

Other methods could also be considered that apportioned the interference by time or locations.

Furthermore, the possible presence of UWB emissions can be accommodated within this apportionment process by either increasing the total level (I_{agg}) or reducing the level of the individual contribitions (I_s).

4.5.3 Spectrum White Space

In bands were there is currently only limited deployment of SURs, it might be suggested that an operator could propose increasing the amount of interference they generate above the apportionment rules suggested above, where this could tolerated.

Should this be permitted, it would decrease the ability of new entrants to enter and utilise the band. There would therefore be an associated spectrum cost. This should be included in any spectrum pricing mechanism (whether set by an SMO or Ofcom) which should take account of the apportionment rules discussed above.

5 CONCLUSIONS

This section summarises the conclusions of the case studies undertaken under this project. A list of issues raised by these case studies can also be found in Section 5 in the Final Report.

It was found that the separation of rights into SMR and SUR levels was an effective and useful framework within which to undertake the case studies. It was found to be feasible to analyse the interference issues at these two levels separately.

5.1 Case Studies at the SMR Level

It was noted that interference only occurs between SURs, and when there are no SURs there are no interference issues. Therefore the key to management of interference between SMRs is control of the process by which the SURs are introduced.

A number of controls on how SMRs can introduce SURs were considered. For in-band interference the approaches considered were:

- Approach 1: EIRP and deployment area;
- Approach 2: Aggregate PFD on boundary;
- Approach 3: Technical Coordination;

Risks were found in Approach 1 as the aggregation assumptions could prove to be incorrect. Therefore it would be better to manage interference either via aggregate PFD on boundary or via technical coordination. It is noted that technical coordination could be an option negotiated between SMR owners if the costs of software and data exchange were outweighed by the benefits in terms of spectrum efficiency.

Hence aggregate PFD on boundary was suggested as an effective tool to manage in-band interference between SMRs.

It is difficult to predict accurately how aggregate PFD levels will attenuate beyond a boundary and it is acceptable to assume the PFD is constant beyond that point. A technically robust method to derive PFD levels was found to be from the characteristics of typical receivers. Due to variations in traffic and propagation, any aggregate PFD level should be associated with a percentage of time.

Control of out-of-band interference proved more problematic than that for in-band. The following approaches were considered:

- Approach 1: EIRP Mask (with four sub-variations of High EIRP, Low EIRP, Minimum Distance and Urban/Rural);
- Approach 2: OOB PFD Mask;
- Approach 3: Technical Coordination;
- Approach 4: Use of specific standard.

The level to use for the EIRP mask (high) case can be derived from a system's transmit characteristics, while the EIRP mask (low) can be derived from receiver characteristics.

The preferred approach to use depends upon the objectives and priorities of the SMR owner, which are likely to vary depending upon circumstances. For example in frequency bands where point to point FS links operate, technical coordination might be preferred. However in bands where systems are likely to be low power, the EIRP Mask (low) approach might be preferred. The benefit of the overall framework is to give the SMR owners the flexibility to choose which suites them best.

SMRs based upon existing licences can initially be defined based upon current licence conditions. For newly available spectrum, the preferred option will depend upon the objective for the band. For example if the objective is:

Simplicity – then manage via the EIRP mask (high), selecting the level from the transmit characteristics of the system. However use of the EIRP mask (high) approach can increase the risk of interference.

Low Risk – a low risk approach is to use the EIRP mask (low), selecting the level from the receive characteristics of systems in adjacent bands and a suitably small separation distance. However this can constrain development and lead to inefficiencies.

Spectrum Efficiency – an approach that can produce high spectrum efficiency is to mandate the use of technical coordination to check the introduction of each SUR. However this can introduce a procedural overhead in cases where there is frequent re-configuration.

No single approach was found to combine technology neutrality with simplicity, low risk, and high spectrum efficiency. Alternative methods to manage out-of-band interference were investigated and the OOB PFD mask was identified as a possibility. It allows re-configuration while protecting adjacent operators from interference. However this approach is untested and could be complex to define and calculate.

5.2 Case Studies at the SUR Level

Within a framework of SMRs, there was value in considering case studies involving SURs because:

1. Some existing licences classes will be mapped to SURs with Ofcom as the band manager;
2. Technical coordination of SURs is one possible method to manage interference between SMRs (both in-band and out-of-band);
3. It gives greater understanding into the way the SMR / SUR framework manages interference.

It was noted that defining SURs in detail allowed for the technical examination to occur that can lead to high technical spectrum efficiency. This examination involves defining parameters such as transmitter locations, EIRP, gain patterns, and activity and receiver characteristics including locations, filtering mask, and gain patterns.

It was not considered useful to use PFD as a parameter at the SUR level. As noted above it is hard to make predictions about how aggregate PFD decreases beyond a boundary and so conservative assumptions must be made such as it remains constant. PFD on boundary represents an aggregate from many SURs and is hence relevant to the SMR level and not associated with an individual SUR.

It was noted in interference analysis that the effect of changing some SUR parameters is hard to predict due to the non-linearity of radio communication models. It is therefore necessary to undertake interference analysis to determine if a proposed CoU is acceptable.

In order to determine if a predicted interference level is acceptable it is necessary to have a threshold to compare against, namely the indicative interference level or IIL. This does not represent a right, but gives the SUR owner the confidence that their needs as specified in the IIL will be taken into account during the planning process.

The planning and CoU process should ensure that emission levels and IILs are consistent and only approve changes that do not lead to inconsistencies.

As the IIL gives the aggregate level of interference at a receiver it is necessary to define apportionment rules to identify how much interference each SUR is permitted to cause into another. These rules should defined by the SMR owner and made available to SUR owners.

This process could be applied to the SURs within a band managed by one SMR or between SURs managed by different SMRs.

A CASE STUDY: MOD AND COMMERCIAL OPERATOR

A.1 Background

This scenario related to sharing between a public user of spectrum, the MoD, and a commercial operator. The scenario was devised based upon general principles rather than any specific technology or actual usage by the MoD. Parameters selected were not based upon any known real or planned networks and have only considered in-band interference paths.

The scenario considered the implications of geographic sharing between radars and other services at 1.4 GHz. The premise was that the MoD used the band for radar as part of training exercises. Historically there were a number of test ranges all requiring use of radars located across Scotland, as shown in the figure below.

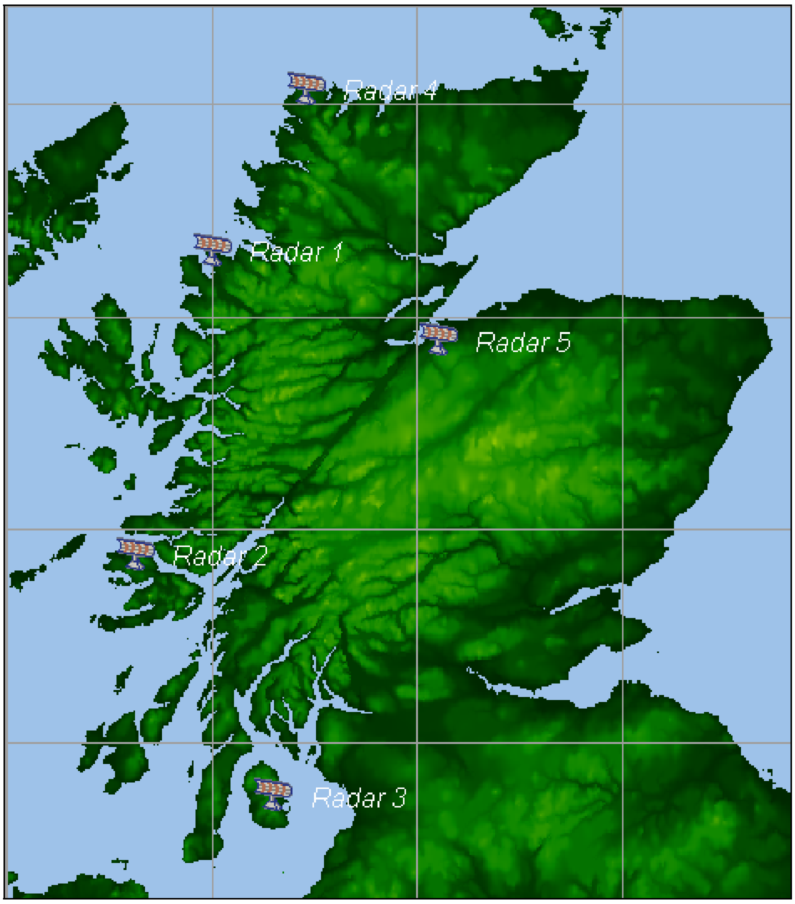

Figure A-3: Location of Radar Sites

The objective of the case study is to compare alternative methods by which the spectrum usage rights of the two services could be defined and the resulting impact in terms of protecting the MoD site and efficient use of spectrum.

The following characteristics are assumed for the radar:

Transmit power	20 kW
Bandwidth	50 MHz
Peak gain	30 dBi
Receive losses	1 dB
Receiver noise temperature	300 K[3]
I/N threshold	-10 dB
Maximum time can exceeded threshold	10 %

Table A-3: Radar Parameters

Note that all the parameters for the radar systems have been constructed for this case study and are not based upon any known or planned system.

In addition it was assumed that as part of a rationalisation of training facilities, all but one of the radar sites (the furthest North) were closed. There were therefore two radar deployment models considered namely all 5 or just one (“Radar-4”).

The band could also be used by mobile systems, in particular for base stations (BS) at fixed locations. These are assumed to have characteristics as in the table below based upon GSM:

Base Station maximum EIRP / channel	62 dBm
Channel Bandwidth	200 kHz
Mobile Receiver noise temperature	600 K
Mobile I/N threshold	-10 dB
Maximum time can exceeded threshold	10 %

Table A-4: Mobile Network Parameters

The sharing issue related to the BS transmit to mobile path: similar analysis could also be done for the mobile transmit case.

The issue is then how to construct SURs such that both can operate without fear of legal interference problems. There were two such paths to consider:

a) From the mobile system’s BS into the radar. A particular problem here is there will be an aggregation effect from the potentially large numbers of transmitters.

b) From the radars into the mobile receivers.

Given this environment, a number of approaches to defining the mobile system SMR are feasible. The following were considered:

[3] While this is low for radar systems it could be applicable to quote such a figure to protect future systems

1) Define the maximum BS EIRP and a boundary one side of which BS can be deployed;
2) Define the maximum BS EIRP and a registration or coordination process for each BS which would give a go/no go decision;
3) Define the maximum BS EIRP and define aggregate PFD levels not to be exceeded on a boundary.

Note that all approaches include the definition of maximum EIRP: this will be required for other reasons such as management of out-of-band interference, site clearance etc.

All analysis in this section was done using the ITU-R Rec. P.452 propagation model and a terrain database. The percentage of time to use in this model was taken from the receiver protection requirements – in this case p = 10%. Propagation paths were assumed to be fully correlated so that the same percentage was used in all loss calculations.

A.2 Approach 1: Maximum EIRP plus Deployment Boundary

This approach controls interference by definition of a boundary and maximum EIRP. The mobile operator can deploy BS anywhere within the area one side of the boundary and transmit up to the defined EIRP.

The location of the boundary will depend upon the need to protect both services. It is easier to do the calculation from the radar into the mobiles as the former's parameters are known (though they may not be disclosable). For the radar sites defined the figure below shows the contour where the I/N just meets the mobile's interference threshold of -10 dB.

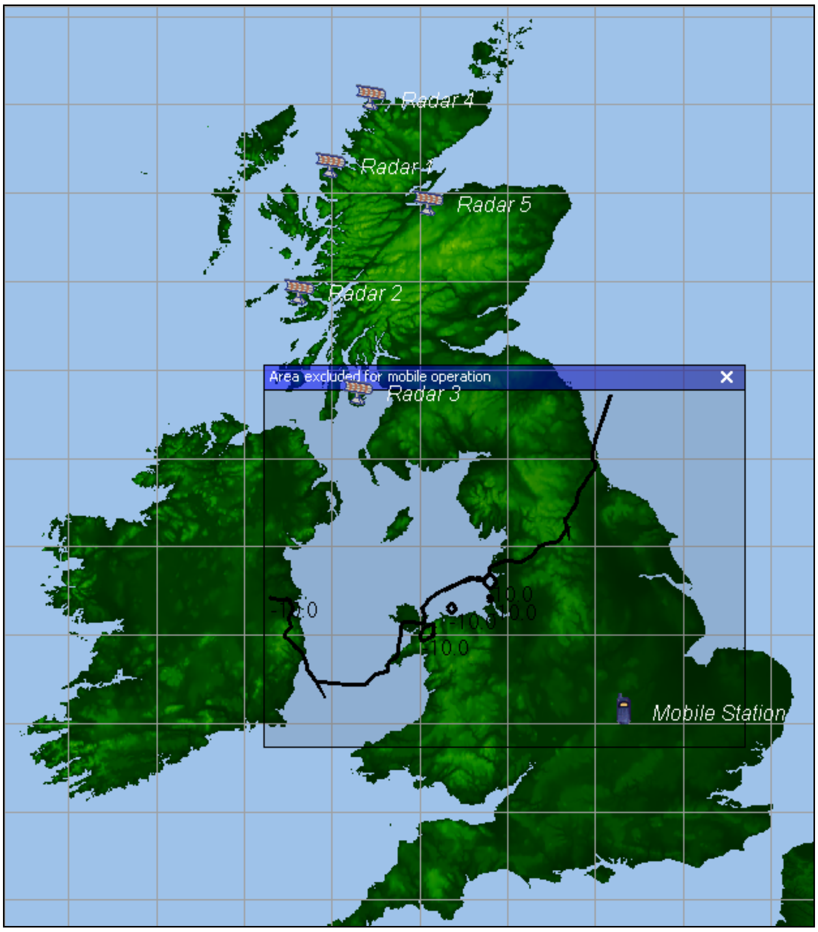

Figure A- 4: Boundary where interference from radar meets mobile receiver interference threshold

To determine the converse case – how to protect the radar sites – the minimum path loss was calculated based upon the single entry I/N equation, re-arranged as follows:

$$L_{452} = \left(EIRP + G_{rx} - L_{rx}\right) - 10\log_{10}\left(kTB\right) - \left(I/N\right)$$

As in practice there could be large numbers of transmitters, then the required path loss will be higher. This adjustment factor typically will be derived from simulations based upon assumptions as to deployment locations, densities, service etc. For this example, the factor was assumed to be 10 dB, resulting in a required minimum path loss of 232 dB from the exclusion zone boundary to *any* of the radar sites.

Note that this figure is dependent upon the assumptions as to EIRP (defined in the licence) and aggregation / deployment expected (which would not).

The figure below shows the contour line beyond which operation of mobile systems would be permitted. It can be seen that a large section of the UK is sterilised, with only the south-east region (between the Wash and the Severn River) available for use.

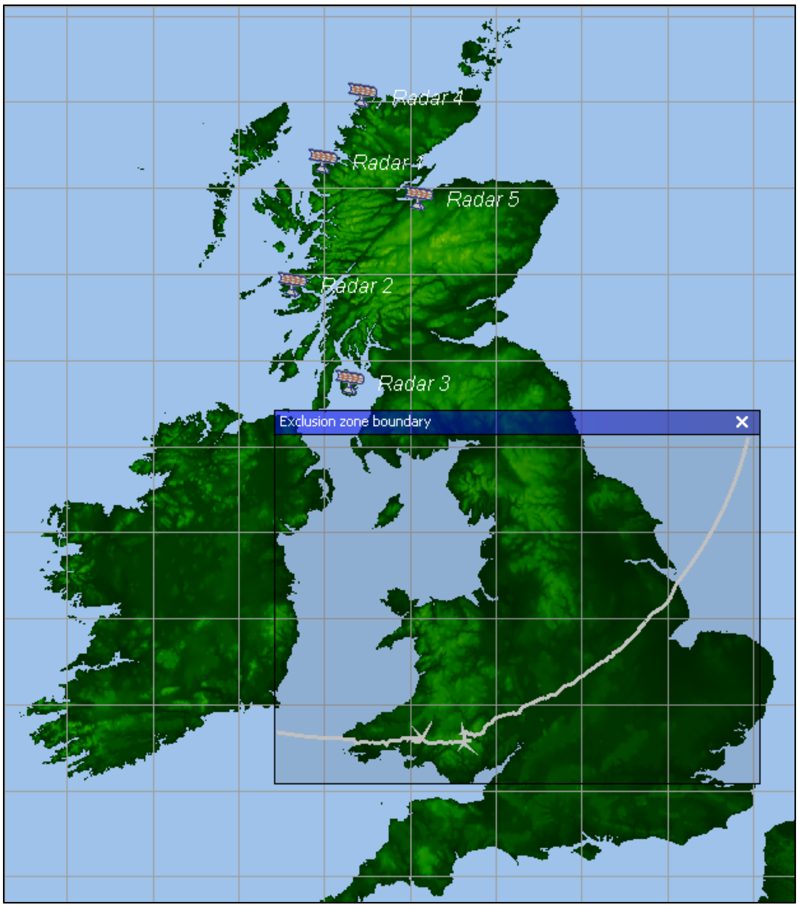

Figure A-5: Boundary beyond which BS could be deployed

It can be seen that the boundary to protect the radar must be further south than one to protect the mobiles. This is because the radar service is more susceptible to interference.

A licensing regime could therefore be used such as:

- Base Stations may not be deployed beyond a line connecting the Seven River to the Wash;
- The maximum EIRP of any single transmitter should not exceed 62 dBm;
- The licensee should expect aggregate interference from the radar to be no more than -157.8 dBW[4] at a mobile receiver located within the deployment area.

When all but one of the radar sites was closed the exclusion zone boundary changes. The figure below shows the boundary for BS deployment:

[4] Derived from I/N threshold and values in Table 2

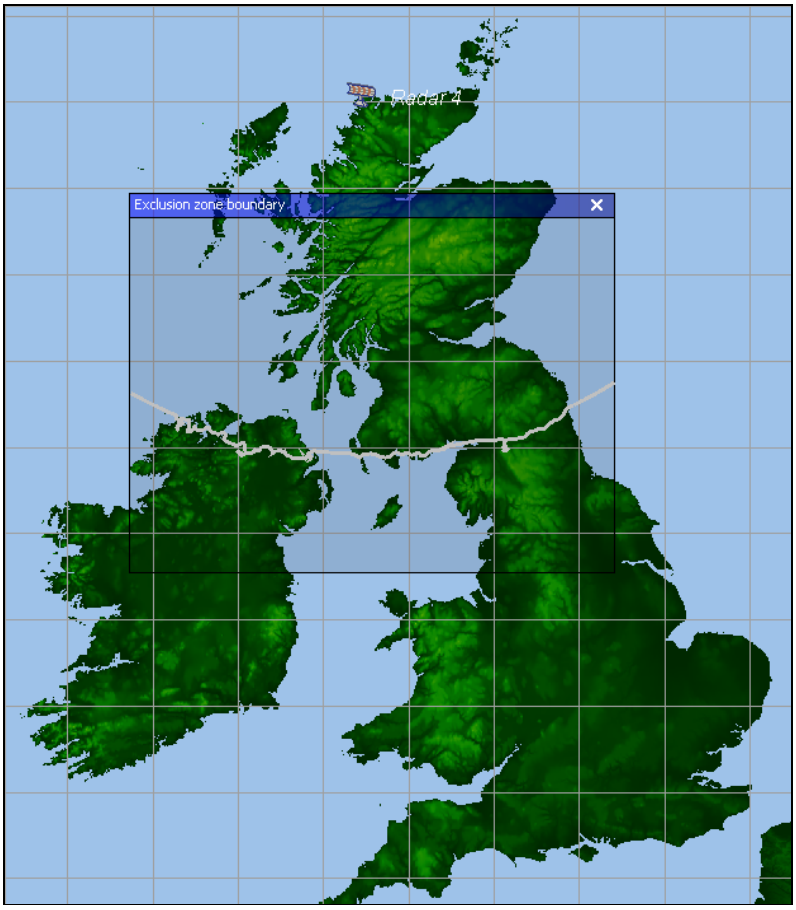

Figure A-6: Boundary beyond which BS could be deployed after Radar site closure

The figure below shows the area where the mobile systems interference thresholds will be met:

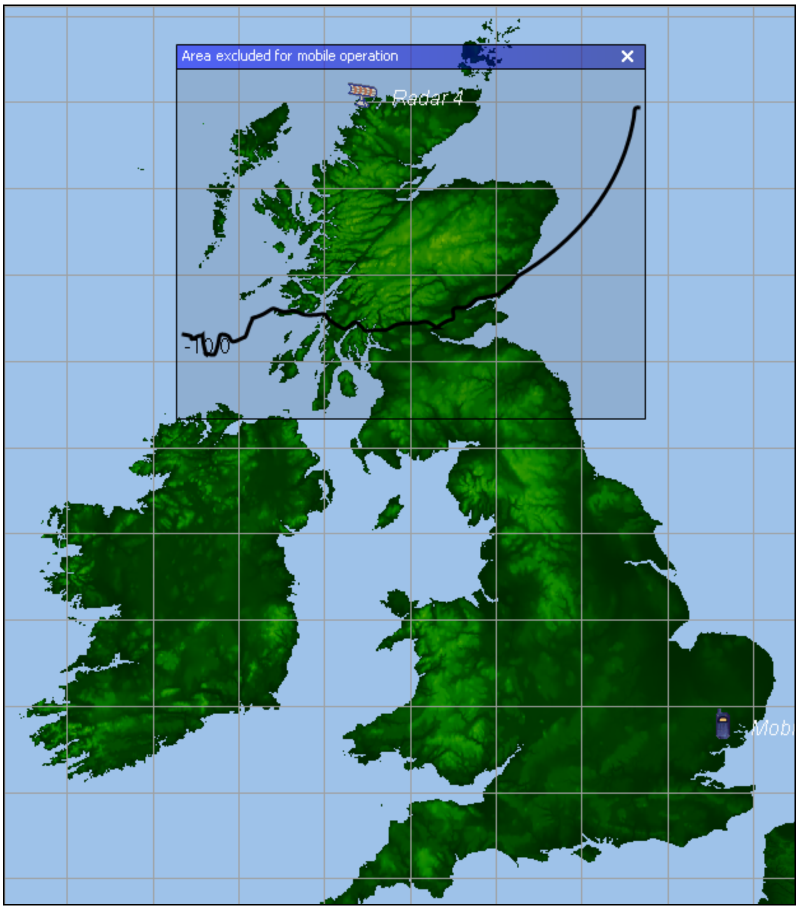

Figure A-7: Boundary where interference from radar meets mobile receiver threshold after radar site closure

This approach reduces the area excluded significantly, and this area could then be used by commercial operators with suitable compensation to the MoD.

Summary of the EIRP and Boundary Approach

- This approach is relatively transparent in its definitions and hence straightforward to enforce;
- The calculation of boundary to protect the radar required assumptions about the aggregation effect (i.e. additional 10 dB) from large numbers of BS, which could be wrong;
- The calculation of boundary to protect the mobile required information about the radar sites and parameters that might not be available for disclosure.
- These two calculations are unlikely to result in boundaries that are at the same location;
- For some auctions the boundaries will be fixed by other constraints – for example regions – and hence this approach would not ensure protection of systems against interference across the boundary unless there was a clearly defined quiet zone between the two licences;

- This approach might be more applicable to scenarios like this one where this is the ability to choose where the boundary should be in such a way as to control interference.

A.3 Approach 2: Maximum EIRP plus BS Registration / Coordination

This approach is based upon registration of each BS together with a maximum EIRP level. The registration can be combined with automated check to ensure the proposed location and power levels would not cause unacceptable levels of interference into the radar. In addition it could check the spectrum quality level at the proposed location.

The parameters for each site could vary and be specified in registration, and hence it would not be necessary to take worst case assumptions such as transmitting at the maximum power in the licence.

This approach could be of assistance to an operator that wishes to deploy within the boundary defined above. In order to do this each site could be coordinated directly with the MoD, with individual locations registered and the power reduced. Hence with a reduced EIRP of 6 dBW around 50 base stations can operate co-frequency in each channel, as in the figure below.

The figure below also shows the line where interference from the radar would reach an I/N = -10 dB for 10% of time or more. It can be seen that individual site registration and coordination allows deployment close to the predicted limit (compared to previous figures), and hence there is high technical spectrum efficiency.

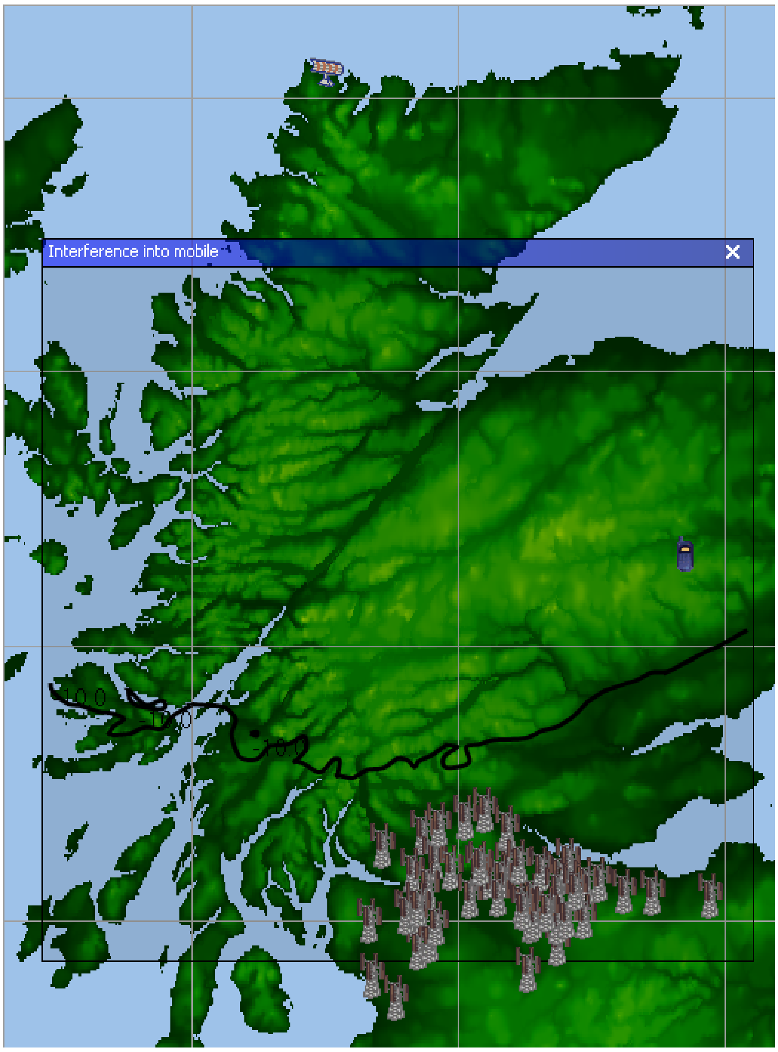

Figure A-8: Boundary of interference into mobile network and example BS deployment

This approach is more typical of SUR rather than SMR and requires good communication between the MoD and commercial operator. In effect the MoD would be operating as a Band Manager, licensing individual stations. This might be an unwanted additional task.

In addition, it would be hard to keep confidential parameters of the radar network as these could be reverse engineered by specialists with access to the coordination tool.

This could be an area for the employment of the trusted third party as proposed by the Cave Audit of Public Spectrum.

Summary of the EIRP plus BS Registration / Coordination Approach

- This approach can result in high technical spectrum efficiency;
- It requires close co-operation between the MoD and mobile operator
- One solution would be for the MoD to act as Band Manager issuing SUR Licences to the mobile operator for each BS.

- These activities could be facilitated or managed by a trusted third party;

Note: it was found that in the analysis for this scenario, the difference between the worst single entry and aggregate was 13.6 dB – more than assumed in the previous approach.

A.4 Approach 3: Maximum EIRP plus Aggregate PFD on Boundary

One approach to manage aggregation of interference is to define an aggregate PFD level not to be exceeded. However it is in practise not possible to predict how PFD levels will decrease beyond a boundary. Therefore it is dangerous to set PFD threshold levels at anything other than the minimum required to protect the receivers. Hence typically these constraints are of the form "*not to be exceeded at any point at or beyond the boundary".*

The PFD level to use can be derived from the I/N threshold, the receive gain and the noise temperature as follows:

$$PFD = I + 10\log_{10}\frac{4\pi}{\lambda^2} - G_{rx} = \frac{I}{N} + 10\log_{10} kTB + 10\log_{10}\frac{4\pi}{\lambda^2} - G_{rx}$$

In this case this equates to a PFD = -183.4 dBW/m^2/4 kHz.

As signal levels can vary due to propagation effects, it is appropriate to define the PFD for an associated percentage of time. While often this is based upon the median level (to assist in measurement) this can result in the risk of levels of interference above the threshold. Therefore it is suggested it would be more appropriate to use the percentage of time from the receiver performance requirements – in this case 10%.

In addition as the PFD can vary by height, it is useful to define a maximum value.

Therefore the MoD could define a boundary line and state that the aggregate PFD on or beyond this boundary must be exceed not this value. The operator would then have the flexibility to deploy their stations as long as this PFD level is not exceeded. There could also be other constraints – such as ensuring the EIRP is within the licence terms – in order to manage the blocking out-of-band path.

The boundary line would be selected to protect the radar sites: for example the line of latitude = 55°N could be chosen.

In addition the licence could also give the mobile systems an indication (not binding constraint) of the level of interference that they can expect from the radars on or beyond this boundary. Again this could be defined using aggregate PFD on boundary, though this case received PFD. As before it would be assumed that the PFD could be constant beyond (i.e. within) the boundary.

Hence the licence conditions could be:

- The maximum EIRP of any single transmitter should not exceed 62 dBm;

- The aggregate transmitted PFD at or beyond the boundary of the line of 55° North **should not exceed** -183.4 dBW/m^2/4 kHz at any height up to 30m for more than 10% of the time;
- The aggregate received PFD at or within the boundary of the line of 55° North **is expected to not exceed** -150.4 dBW/m^2/4 kHz[5] at any height up to 2m for more than 10% of the time.

The figure below shows the calculations for an example BS deployment of where:

a) the aggregate transmitted PFD from the BS equals -183.4 dBW/m^2/4 kHz;

b) the aggregate received PFD at the mobile equals -150.4 dBW/m^2/4 kHz.

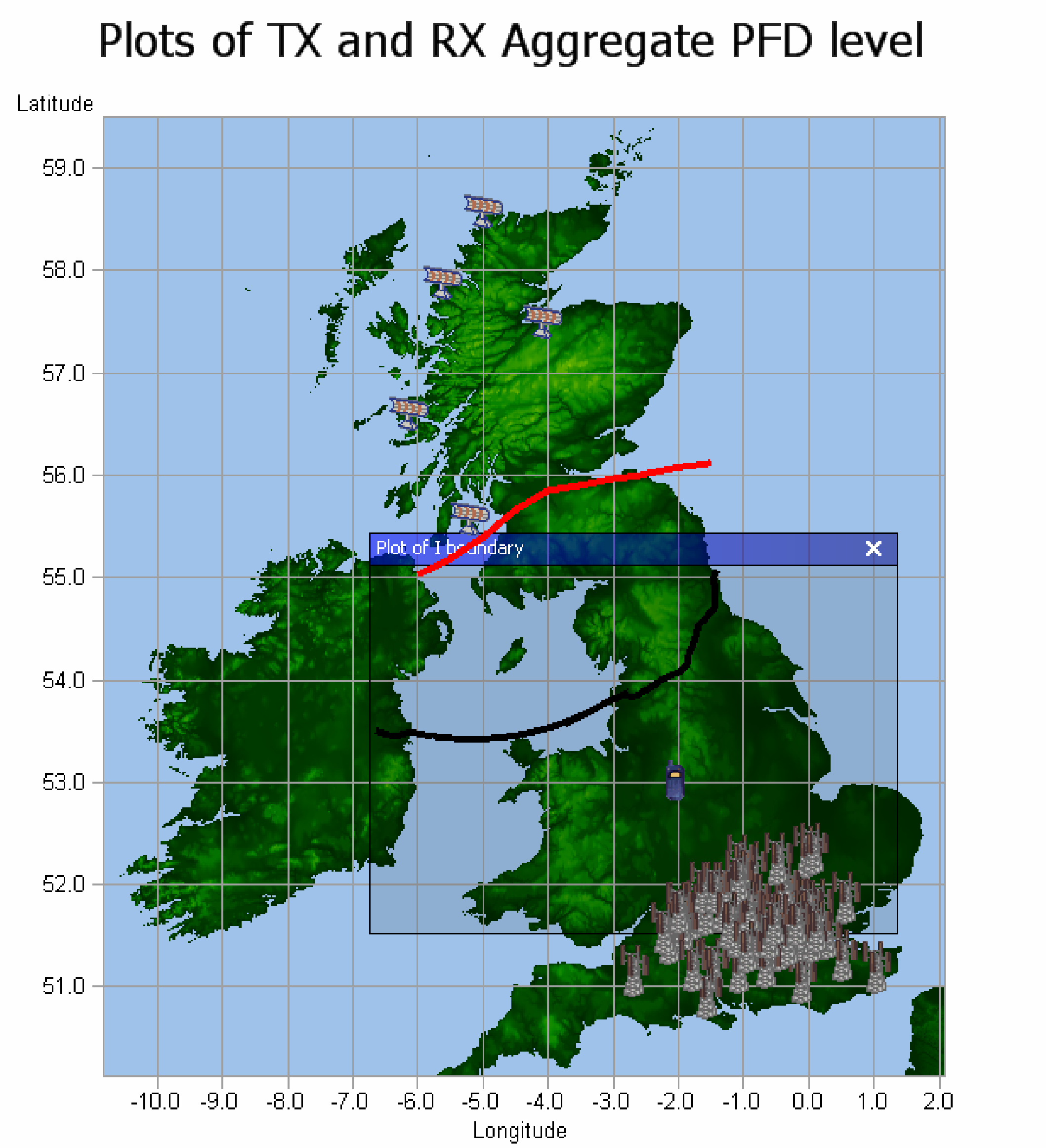

Figure A-9: Plots of TX and RX Aggregate PFD level

[5] Calculated from I/N requirement and using the same equation as before

In this particular case the deployment proposed would produce transmit aggregate PFD levels at 55°N at levels higher than those in the licence of -183.4 dBW/m^2/4 kHz and would therefore not be acceptable. However it should also be noted that this deployment would not actually cause interference into the radar: here the boundary has been defined some distance from the radar sites.

In theory the transmit aggregate PFD level could be defined at a set of point – the locations of the radars. This would be increase technical spectrum efficiency and facilitate sharing.

However it would also require the characteristics of the radar to be both disclosed and unchanging. For operational reasons this might not be desirable. Therefore even though it is less efficient (in technical spectrum terms) to have the boundary separated from the sites to be protected by a significant distance, this could preferable.

The position of the boundary could therefore balance between:

Closer in: more technical spectrum efficiency, more spectrum available to the mobile operator;

Further away: more flexibility, more protection of sensitive parameters;

The position of the boundary line therefore can reflect the various needs and requirements of stakeholders, and represent a good starting point for negotiations.

In the case that radar stations are closed then there would be scope to change the licence terms by moving the boundary – for example to 56°N. In this case, as can be seen in the figure below, the deployment of BS previously considered would now be acceptable.

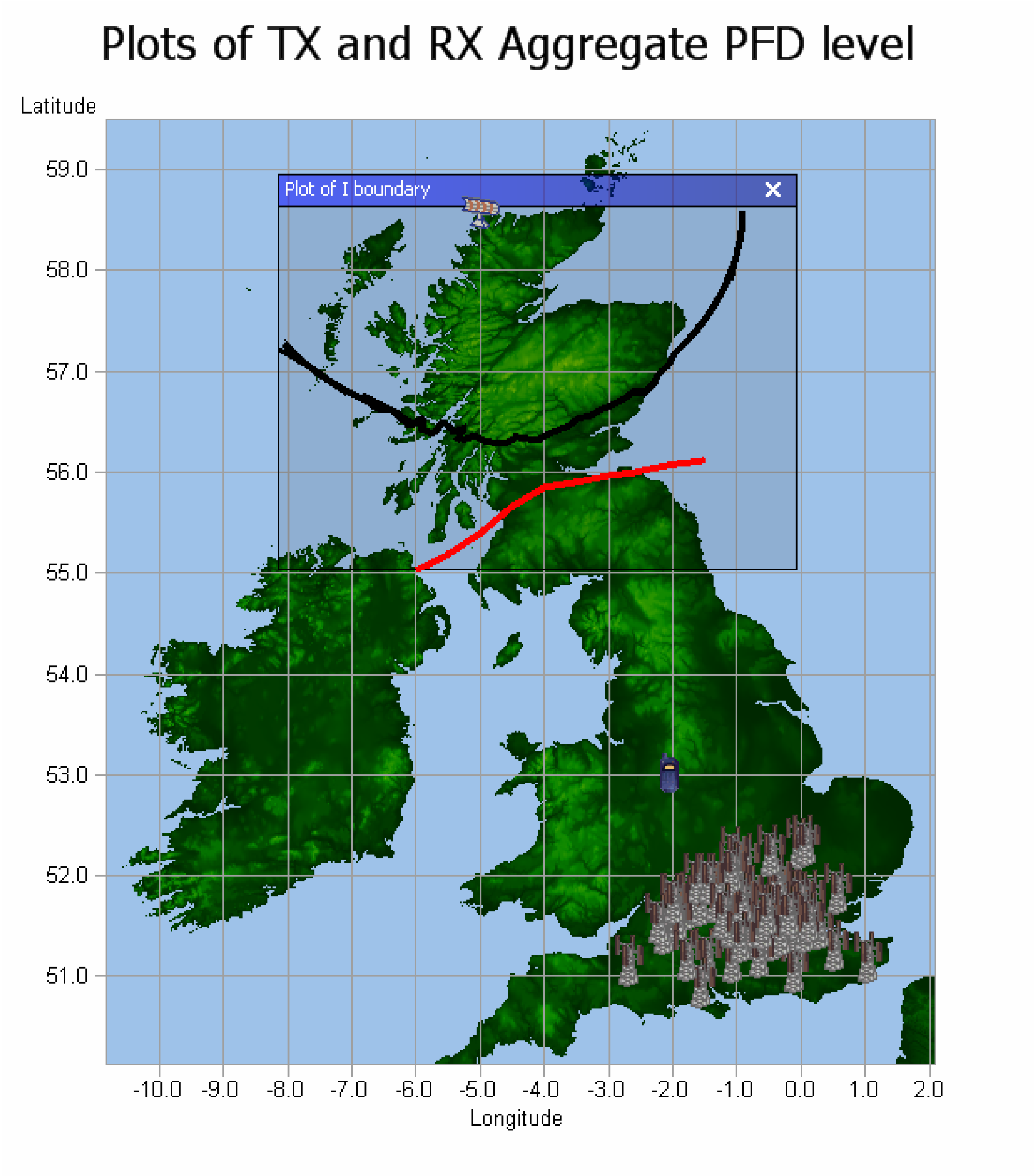

Figure A-10: Plots of TX and RX Aggregate PFD level

Summary of the EIRP plus Aggregate PFD on Boundary Approach

- This approach gives the operator significant flexibilities in deploying their systems as long as they ensure the aggregate TX PFD remains within licence conditions.
- The receive aggregate PFD gives a good indication of spectrum quality;
- In both cases the PFD level would have to be assumed to be constant beyond the boundary (as in the figure below).

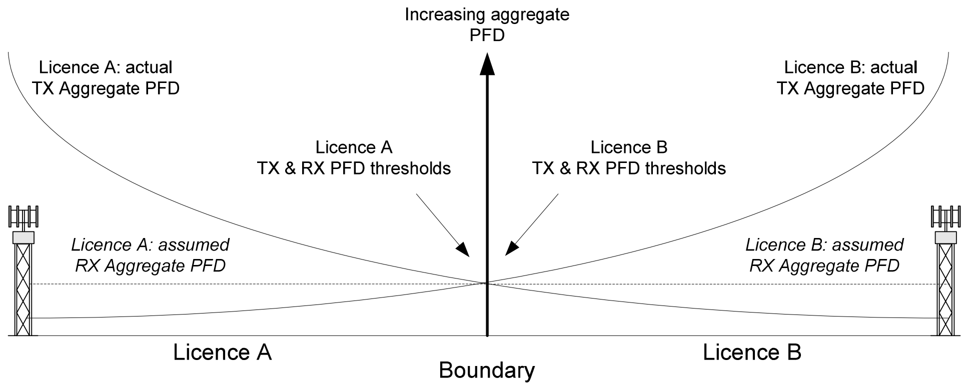

Figure A-11: TX and RX PFD Thresholds on and beyond the Boundary

- Assuming Aggregate PFD is constant beyond the boundary is a technically robust assumption which could reduce technical spectrum efficiency;
- In boundaries between two identical services, the TX and RX PFD levels are likely to be the same (as in the figure above);
- In boundaries between dissimilar services, the TX and RX PFD levels can be expected to be different;
- It is important that the PFD level has an associated percentage of time (see section below);
- The boundary can be moved to hide specific details about a system (transmitter or receiver characteristics) and to increase operational flexibility but at the cost of technical spectrum efficiency;
- The position of the boundary can reflect the various needs and requirements of stakeholders, and represent a good starting point for negotiations.

Issues relating to PFD and Percentage of time

It should be noted that propagation effects can result in wide variations in signal levels. It is therefore important that the PFD on boundary has associated with it a percentage of time.

For example, the figure below shows for an example BS deployment, the location of the line where the TX aggregate PFD just meets the radar threshold of -183.4 dBW/m^2/4 kHz for both 10% and 50% of the time.

It can be seen that there is significant difference between defining the PFD level for 10% of time and 50% of time.

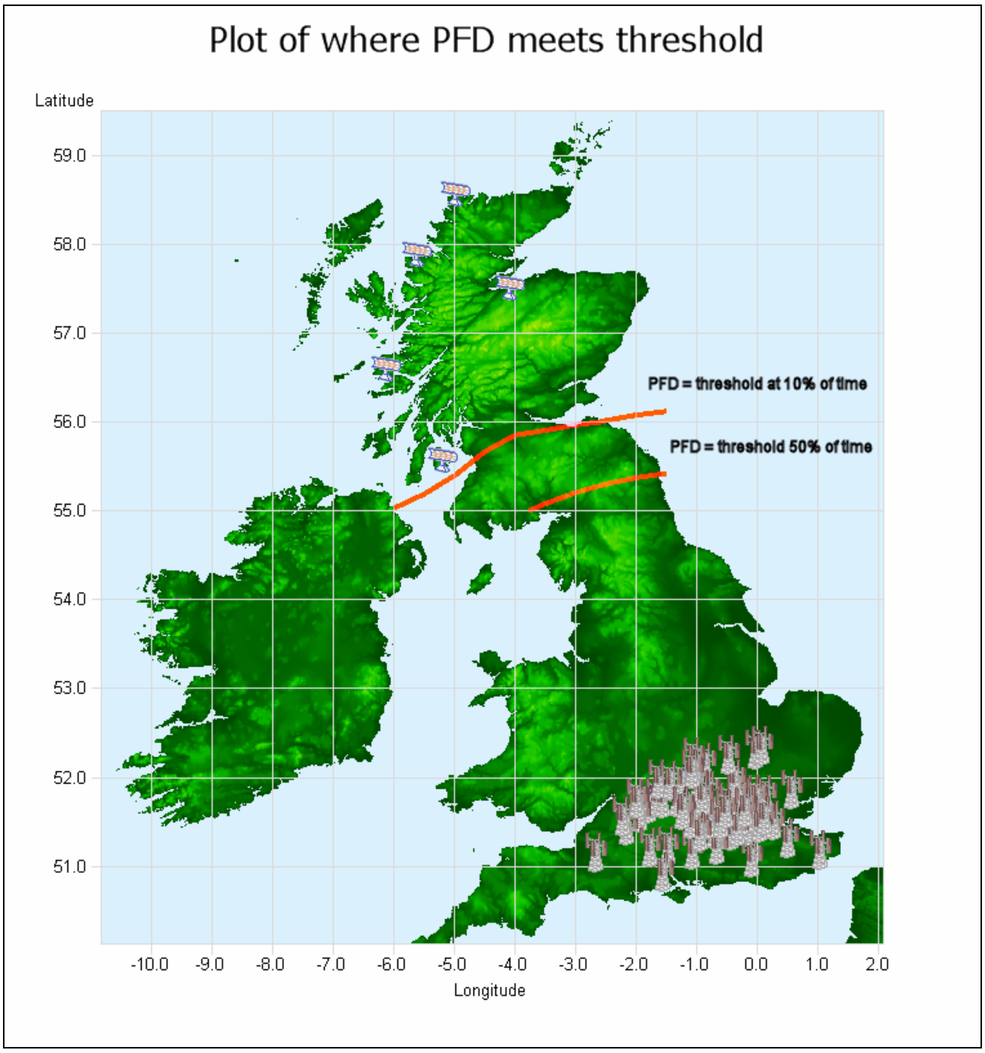

Figure A-12: Difference between p=50% and p=10%

B CASE STUDY: TWO MOBILE SYSTEMS

B.1 Background

This scenario related to band sharing between two mobile operators in which they are co-frequency but geographically separated. A number of approaches to defining the mobile system licence are feasible. The following were considered:

1) Define the maximum BS EIRP and one or more boundary lines;
2) Define the maximum BS EIRP and a registration or coordination process for each BS which would give a go/no go decision;
3) Define the maximum BS EIRP and define TX and RX aggregate PFD levels not to be exceeded on a boundary.

The licences are assumed to have separate bands for the uplink and downlink direction (mobile transmit and base station transmit respectively). In this section it is assumed the uplink direction is low power mobile and so only minimal restrictions are required.

Note that all approaches include the definition of maximum EIRP: this will be required for other reasons such as management of out-of-band interference, site clearance etc.

B.2 Approach 1: Maximum EIRP plus Deployment Boundary

This approach controls interference by definition of a boundary and maximum EIRP. The mobile operator can deploy BS anywhere within the area one side of the boundary and transmit up to the defined EIRP. The licence conditions would be similar to:

Downlink band:

- The maximum EIRP of any single fixed BS should not exceed X dBm averaged over a bandwidth of Y kHz;
- The licensee can deploy BS anywhere within geographical region Z;

Uplink band:

- The licensee can support mobile devices communicating with any legally deployed BS as long as the EIRP of any single transmitter is less than W dBm averaged over a bandwidth of Y kHz.

As can be seen by the figure below, there is the danger of legal interference from one licensee into another.

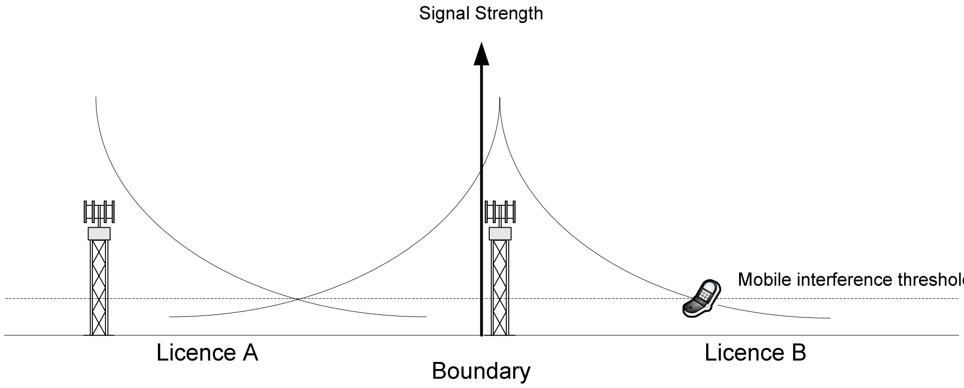

Figure B-1: EIRP + Boundary

In this figure, Licensee B has deployed a BS just on its side of the boundary between it and Licence A. Its signals therefore will cause interference into Licence A receivers close to the boundary. It would not be possible in this scenario to define a useful maximum level of interference.

However similarly A will be able to deploy its BS close to the boundary causing interference into B. This could incentivise both to enter into negotiations, which could be used to agree methods to operate closer to the boundary.

It could be possible to define minimum levels of spectrum quality by separating the boundaries of Licence A and B as in the figure below.

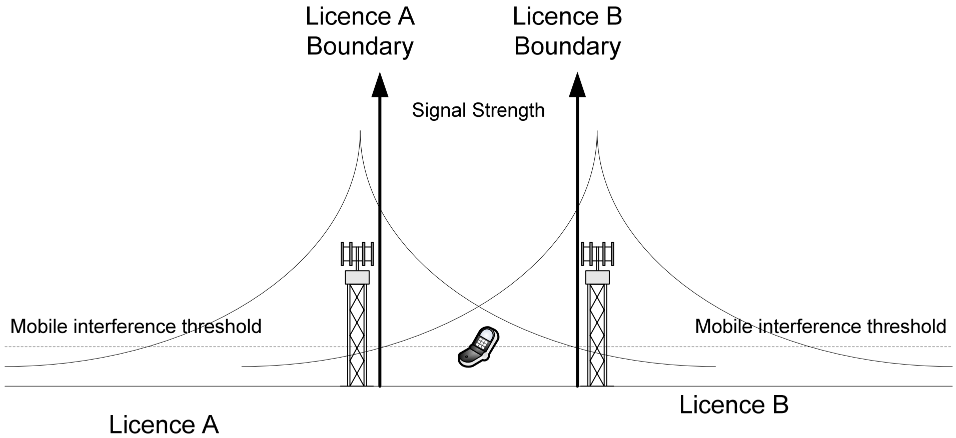

Figure B-2: EIRP plus two boundaries

This approach can ensure (with suitable separation) that each has both TX rights and an appropriate indication of receive interference levels. The separation distance would be calculated based upon assumptions e.g. on aggregation. These assumptions could be wrong – either pessimistic (resulting in inefficient use of spectrum) or optimistic (resulting in interference).

The area between would be owned by neither licensee – in theory like a guard band it would be owned by Ofcom. However there would be some value as low power short range systems could still operate between the boundaries while avoiding causing or suffering interference.

The licence conditions could then read:

Downlink band:

- The maximum EIRP of any single fixed BS should not exceed X dBm averaged over a bandwidth of Y kHz;
- The licensee can deploy BS anywhere within geographical region Z;
- The interference from co-frequency licensees into isotropic mobile receivers is not expected to exceed V dBm averaged over bandwidth of Y kHz for more than P_1 percent of time

Uplink band:

- The licensee can support mobile devices communicating with any legally deployed BS as long as the EIRP of any single transmitter is less than W dBm averaged over a bandwidth of Y kHz.
- The interference from co-frequency licensees into BS with peak gain T dBi is not expected to exceed U dBm averaged over bandwidth of Y kHz for more than P_2 percent of time

Because the two boundaries are separated by a known distance it has the benefit that it is possible to calculate interference levels and hence include them in the licence conditions.

While this approach allows inclusion of an interference indication, the result is locations where there is no clear ownership of spectrum and potentially lower overall technical spectrum efficiency. Therefore dual boundaries were not considered for the following two approaches.

Summary of the Maximum EIRP and Deployment Boundary Approach

- This approach is relatively transparent in its definitions and hence straightforward to enforce;
- Having a single boundary could result in interference into receivers at the boundary and therefore make definition of indicative interference levels impracticable;
- Having two boundaries would make it feasible to define indicative interference levels but at the cost of sterilised locations between the licences and with risk that aggregation assumptions were wrong;
- If there was only a single boundary then there could be negotiations between the parties to use spectrum close to the boundary;
- If there were two boundaries then negotiations would not be required but the spectrum would remain fallow with no clear ownership.

B.3 Approach 2: Maximum EIRP plus BS Coordination

This approach is based upon registration of each BS together with a maximum EIRP level. The registration can be combined with automated checks to ensure the proposed location and power levels would not cause unacceptable levels of interference into the other operators. In addition it could check the spectrum quality level at the proposed location.

The licence conditions would be similar to:

Downlink band:

- The maximum EIRP of any single fixed BS should not exceed X dBm averaged over a bandwidth of Y kHz;

Uplink band:

- The licensee can support mobile devices communicating with any legally deployed BS as long as the EIRP of any single transmitter is less than W dBm averaged over a bandwidth of Y kHz.

Coordination of deployment in uplink and downlink bands:

- Deployment of a BS site and associated service area will be subject to a coordination process that includes registration and confirmation within an engineering process that checks the aggregate interference into the receivers of other licences based upon the following:
    - The interference from co-frequency licensees into isotropic mobile receivers should not exceed V dBm averaged over bandwidth of Y kHz for more than P_1 percent of time
    - The interference from co-frequency licensees into BS with peak gain T dBi should not exceed U dBm averaged over bandwidth of Y kHz for more than P_2 percent of time

This approach would require the definition of a coordination procedure and implementation of software. This could be developed as part of an industry code of practice agreed between licensees.

The code of practice could also take account of other issues – for example how to manage conflicts between licensees that both want to deploy BS near their boundaries. A number of approaches could be considered – for example first come first serve, or equal share (in time and/or bandwidth) to all parties.

Any process that involves registration must contend with the danger of parties submitting excessive numbers of registrations to slow others or to grab notional rights by filing for “paper base stations”. The process should provide mechanisms to hinder this, which could include requirements to bring into use within a certain timescale or financial incentives such as deposits.

This approach typically results in high technical spectrum efficiency, as a lot of information is known. However it requires there to be an agreed coordination procedure and software that is able to take account of the deployment requirements during the licence period. This approach could include the option for direct negotiation between parties.

Negotiation is assumed to be available by default in most regulatory regimes, and one result of negotiation could be a coordination approach as described here.

However mandating a formalised approach such as this in the licence conditions could add value to the licence as there would be less opportunity for hold-outs or blocking negotiating tactics.

Summary of the Maximum EIRP and BS Coordination Approach

- This approach results in high technical spectrum efficiency and low risk of legal interference;
- It requires a high degree of transparency of other licensee's use of radio spectrum;
- There would need to have a coordination process available together with suitable software tools;
- A key part of the coordination process would be the rules by which conflicting requirements to deploy near the boundary are handled;
- This process could be defined as part of the licence at auction or agreed between parties;
- This approach could include the option of negotiation;
- The availability of low cost automated tools could reduce the need for negotiation to all but the most sensitive cases.

B.4 Approach 3: Maximum EIRP plus Aggregate PFD on Boundary

One approach to manage aggregation of interference is to define an aggregate PFD level not to be exceeded. It is in practise not possible to predict how PFD levels will decrease beyond a boundary. Therefore typically these constraints are of the form "*not to be exceeded at any point at or beyond the boundary".*

As signal levels can vary due to propagation effects, it is appropriate to define the PFD for an associated percentage of time. In addition as the PFD can vary by height, it is useful to define a maximum value.

Therefore the licence could state that the aggregate PFD on or beyond a boundary line must be exceed not a specified value. Each operator would then have the flexibility to deploy their stations as long as this PFD level is not exceeded (and the EIRP is within the licence terms).

In addition the licence could also give each licensee an indication (not binding constraint) of the level of interference that they can expect from other mobile licences. Again this could be defined using aggregate PFD on boundary, though this case received PFD. As before it would be assumed that the PFD could be constant beyond (i.e. within) the boundary.

The figure below gives an example of the two PFD levels meeting on the boundary.

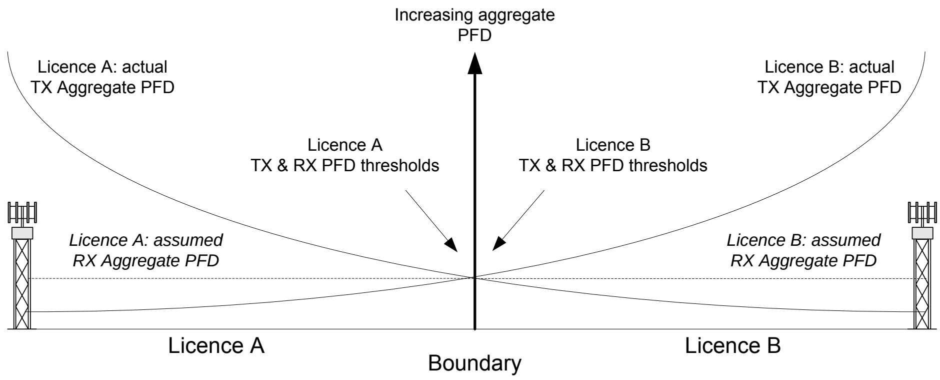

Figure B-3: TX and RX PFD thresholds on Boundary

Hence the licence conditions could be:

Downlink band:

- The maximum EIRP of any single fixed BS should not exceed X dBm averaged over a bandwidth of Y kHz;
- The aggregate transmitted PFD at or beyond the boundary **should not exceed** W_1 dBW/m^2/4 kHz at any height up to H_1 m for more than P_1 % of the time;
- The aggregate received PFD at or within the boundary **is expected to not exceed** W_2 dBW/m^2/4 kHz at any height up to H_2 m for more than P_2 % of the time.

Uplink band:

- The licensee can support mobile devices communicating with any legally deployed BS as long as the EIRP of any single transmitter is less than Z dBm averaged over a bandwidth of Y kHz.

It could be argued that with TX PFD on boundary conditions there is no need to define RX PFD interference indications. This is particularly the case where (at least initially) there are the same conditions applicable to all licences in the band – i.e. the TX PFD limit is the same for both operators either side of a boundary.

However one benefit in having both TX and RX limits would be that it would be clear if one party increases its TX limit then other parties need to agree. The victim licensee could have the option to register their agreement to their neighbours increase in power without changing their licence.

There is an implicit assumption in having both TX and RX aggregate PFD limits set the same is that only the adjacent licensee contributes significantly to the aggregate PFD detected on a boundary. This is because the TX PFD is the aggregate from all transmitters within a licence, while the RX PFD is the aggregate from all licences[6].

The PFD level in the licence could be taken as either:

High level: transmitters are permitted near the boundary and there would be the potential for sterilised zone within the adjacent licence where there would be interference;

Low level: transmitters would not be permitted near the boundary and so there would be a sterilised zone within the boundary where transmitters would exceed the PFD levels[7].

Of the two extremes there are arguments in favour of the latter, namely low level as:

a) It is possible to derive a low PFD level based upon receiver interference thresholds without making assumptions about propagation or aggregation effects;

b) It is not possible to determine the rate at which a high PFD level would decrease and so would introduce uncertainty about actual interference levels;

It is therefore suggested that low PFD levels are used derived from receiver interference thresholds.

Note that negotiations are likely to be required to avoid sterilised spectrum near the boundary. These negotiations could involve the introduction of coordination methods as in the previous approach to manage the spectrum under existing licence terms. In addition negotiation would be required to change any of the licence terms.

Summary of the EIRP plus Aggregate PFD on Boundary Approach

- This approach gives the operator significant flexibilities in deploying their systems as long as they ensure the aggregate TX PFD remains within licence conditions.
- The aggregate RX PFD limit could be included to give confidence to the operator to deploy without fear on unacceptable interference;

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[6] However these definitions could be altered

[7] It should be noted that with a low PFD level, the area near the boundary could still be used even if negotiations failed by decreasing the EIRP until the aggregate TX PFD levels were just met.

- The aggregate RX PFD could be used as a trigger for measurement program as part of enforcement;
- While the PFD level could be set to a range of values, there are benefits in setting it to a value derived from receiver interference thresholds without requiring assumption about propagation or aggregation effects;
- The PFD criteria should have an associated percentage of time and height and be defined as “on or beyond the boundary”;
- Negotiations could be still be required to operate near the boundary unless very low power transmitters were used;
- Any change in PFD level on the boundary would require negotiation.

B.5 Conclusions

This analysis above considered three methods to manage in-band interference:

d) Maximum EIRP plus Deployment Boundary

e) Maximum EIRP plus Coordination

f) Maximum EIRP plus Aggregate PFD on Boundary

All methods considered could be used to manage in-band interference between geographically separated radio systems and each approach has its advantages and disadvantages.

C CASE STUDY: FDD AND TDD

C.1 FDD and TDD Operation in Adjacent Bands

C.1.1 Description of Scenario

This scenario considers coexistence between a Frequency Division Duplex (FDD) and Time Division Duplex (TDD) system operating in adjacent frequency bands and in the same geographic area. It was assumed that there were no guard bands, as is typically the case for the UK 3G assignments. The fixed channel plan complicates the inclusion of guard bands unless an operator with 2 x 5 MHz channels uses only a single one with 2.5 MHz guard bands on either side. As this would reduce technical spectrum efficiency by 50% it is not considered further.

The premise is that two systems, System A and System B, initially both operate using FDD in the 2.5 – 2.69 GHz band, as shown in the figure below.

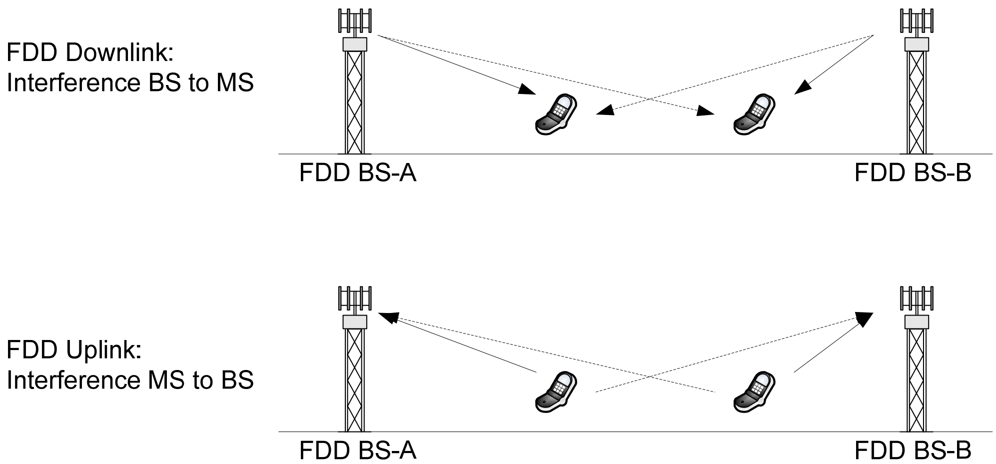


Figure C-1: Adjacent channel scenario before change of use

System B subsequently undergoes a change of use (CoU) from FDD to TDD, giving rise to the potential for out-of-band (adjacent channel) interference, as shown below.

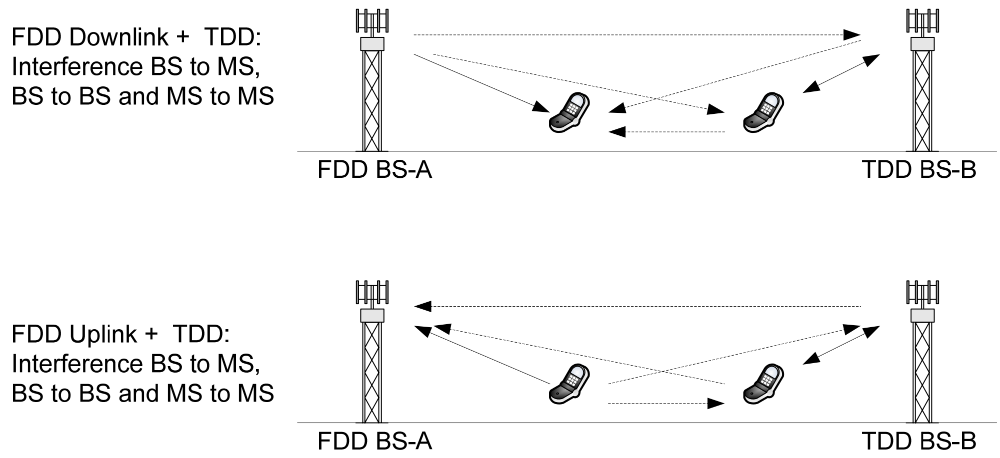


Figure C-2: Adjacent channel scenario after change of use from FDD to TDD

For simplicity, the following interference paths are considered assuming a macro cell (rural) deployment scenario:

Before CoU (i.e. the "As Is" case):

- FDD BS → FDD MS
- FDD MS → FDD BS

After CoU (i.e. the "To Be" case):

- TDD BS → FDD BS
- TDD MS → FDD MS

C.1.2 System Parameters

The technologies considered here are the FDD based IMT-2000 CDMA Direct Spread specification and the TDD based CDMA specification based on the High Chip Rate mode (3.84 Mchip/s).

System Parameters are given in the table below, taken from 3GPP specifications and ITU-R Report M.2030:

Parameter	FDD BS	TDD BS	FDD MS	TDD MS
Height (m)	6[(1)]	6[(1)]	1.5	1.5
Tx power (dBm)	43	43	21	21
Activity ratio[(2)]	1	0.5	1	-11.8
Tx antenna gain (dBi)	15	15	0	0
Rx noise floor (dBm)	-103	-103	-99	-99
Rx antenna gain (dBi)	15	15	0	0
Rx sensitivity[(3)] (dBm)	-121	-109	-117	-105
Adjacent channel leakage ratio[(4)] (dB)	45	70	33	33
Adjacent channel selectivity[(4)] (dB)	46	46	33	33

Table C-1: System Parameters

Notes:

1) Average building height is assumed to be 24m, and the antenna is thus assumed to be 6m above an average rooftop
2) The FDD BS and MS are assumed to transmit continuously; the TDD BS is assumed to transmit 50% of the time and TDD MS 6.66% of time.
3) BS reference sensitivity is specified for a 12.2 kbit/s service, with BER not to exceed 0.001
4) Assuming a minimum carrier separation of 5 MHz (and no guard band)

Adjacent Channel Leakage Ratio (ACLR) is a measure of transmitter performance and describes the relationship between power transmitted in the wanted carrier and power leaking into neighbouring frequency bands.

Adjacent Channel Selectivity (ACS) is a measure of receiver performance and describes the suppression of adjacent channel power.

ACLR and ACS together describe the protection from adjacent channel interference – the Adjacent Channel Interference Ratio (ACIR), calculated as follows:

$$ACIR = \frac{1}{\frac{1}{ACLR} + \frac{1}{ACS}} \qquad \text{(in linear terms)} \qquad (1)$$

C.1.2.1 Interference Criteria

Interference in IMT-2000 systems is usually considered in terms of coverage and capacity losses caused by external interference sources. In the case of coverage loss, the BS density is calculated for different values of the total noise floor (i.e. BS receive noise + external interference) and for different user densities representing a lightly or heavily loaded cell. For capacity loss, the number of BSs is assumed to remain fixed and the increased noise floor results in a lower system capacity.

The total noise floor is given by:

$N_{tot} = N_{BS} + I_{ext}$ (2)

and total interference is given by:

$I = N_{BS} + I_{ext} + I_{int}$ (3)

where N_{BS} = receiver noise floor of the BS

I_{ext} = external interference

I_{int} = internal interference in the victim system caused by both intercell and intracell interference

Acceptable levels of degradation are given in ITU-R Report M.2030 as:

	I_{ext} (dBm)	I_{acc}		Increase in BS density	
		No capacity loss (dBm)	5% capacity loss (dBm)	No capacity loss (%)	5% capacity loss (%)
Macro rural	-114 to -106	-101.6 to -100.2	-101.6 to -100.2	3 to 21	3 to 21
Macro downtown	-100 to -95	-95.1 to -91	-95.1 to -91.5	52 to 129	52 to 117

Table C-2: Interference Criteria

I_{acc} is the maximum acceptable interference at the BS receiver.

For macro cells I_{acc} must be small since the BS must be able to detect a weak MS signal at the cell border with a given C/I. When I_{acc} is exceeded, any further increase in I_{ext} must be compensated by reducing the load on the system (I_{int}), i.e. by dropping calls which consequently reduces capacity. The following inequality must therefore hold:

$I = N_{BS} + I_{ext} + I_{int} \leq I_{acc}$ (4)

The values of I_{ext} in the above table can then be used to estimate required separation distances.

C.1.3 Propagation Model

Typically for this type of analysis a dual-slope line-of-sight (LoS) propagation model is used.[8] This assumes free-space propagation until a breakpoint is reached, after which attenuation increases due to reflections from the ground.

$L = 40.7 + 20 \log(d)$ for $1 \leq d \leq d_{break}$ (5)

$L = 40.7 - 20 \log(d_{break}) + 40 \log(d)$ for $d \geq d_{break}$

where:

$$d_{break} = 4 \frac{h_{Tx} h_{Rx}}{\lambda}$$

[8] Wireless Communications, Principles and Practice. Rappaport, T. S. (1996)

In the above equation h_{Tx} and h_{Rx} are the transmitter and receiver height above average rooftop, λ is the wavelength, d is the distance between transmitter and receiver and d_{break} is the breakpoint associated with the first Fresnel zone.

C.1.4 Sharing Analysis

C.1.4.1 Before Change of Use (the "as is" case)

The following interference paths are considered:

1) Interference from FDD BS Tx into FDD MS Rx

2) Interference from FDD MS Tx into FDD BS Rx

From the above system parameters the following link budgets can be constructed. Since I_{ext} varies between -144 and -136 dBW, both worst case and best case separation distances are shown:

		BS - MS		MS - BS	
		Worst	Best	Worst	Best
BS height	m	30	30	30	30
BS Tx power	dBW	13	13	-	-
BS antenna gain	dBi	15	15	15	15
BS EIRP	dBW	28	28	-	-
BS Rx noise floor	dBW	-	-	-133	-133
BS ACLR	dB	45	45	-	-
BS ACS	dB	-	-	46	46
MS height	m	1.5	1.5	1.5	1.5
MS Tx power	dBW	-	-	-9	-9
MS antenna gain	dBi	0	0	0	0
MS EIRP	dBW	-	-	-9	-9
MS Rx noise floor	dBW	-129	-129	-	-
MS ACLR	dB	-	-	33	33
MS ACS	dB	33	33	-	-
I_{ext}	dB	-144	-136	-144	-136
ACIR	dB	32.7	32.7	32.8	32.8
Required path loss	dB	139.3	131.3	117.2	109.2
d_{break}	M	312	312	312	312
Loss at d_{break}	dB	90.6	90.6	90.6	90.6
Required Separation	**m**	**5,143**	**3,245**	**1,445**	**911**

Table C-3: Deterministic link budgets before CoU

Required path loss is calculated from:

$$L = P_{Tx} + G_{Tx} + G_{Rx} - ACIR - I_{ext} \quad (6)$$

The path loss is then converted to the required separation distance using the dual slope propagation model.

d_{break} = 312 m

If the loss at the breakpoint is less than the required loss, then d > d_{break} and the separation loss is given by rearranging equation (5).

An example calculation for the BS to MS case is given below.

$L = P_{Tx} + G_{Tx} + G_{Rx} – ACIR - I_{ext}$ = 139 dB

d_{break} = 312 m

Loss at d_{break} = 40.7 + 20 log (312) = 90.6 dB

Required separation = 5,143 m

C.1.4.2 *After Change of Use (the "to be" case)*

The following interference paths are considered:

1) Interference from TDD BS Tx into FDD BS Rx

2) Interference from TDD MS Tx into FDD MS Rx

From the above system parameters the following link budgets can be constructed. Both worst case and best case separation distances are shown:

		BS – BS		**MS - MS**	
		Worst	Best	Worst	Best
TDD station height	m	30	30	1.5	1.5
TDD Tx power	dBW	13	13	-9	-9
TDD activity ratio	dB	-3	-3	-11.8	-11.8
TDD Tx antenna gain	dBi	15	15	0	0
TDD EIRP	dBW	25	25	-20.8	-20.8
TDD ACLR	dB	70	70	33	33
FDD station height	m	30	30	1.5	1.5
FDD Rx noise floor	dBW	-133	-133	-129	-129
FDD Rx antenna gain	dBi	15	15	0	0
FDD ACS	dB	46	46	33	33
I_{ext}	dB	-144	-136	-144	-136
ACIR	dB	46	46	30	30
Required path loss	dB	138	130	93	85
d_{break}	m	1248	1248	78	78
Loss at d_{break}	dB	102.6	102.6	78.5	78.5
Required Separation	**m**	**9,573**	**6,040**	**181.5**	**114.5**

Table C-4: Deterministic link budgets following CoU

C.1.5 Observations

The above analysis uses a deterministic approach to calculate separation distance using the method described in ITU-R Report M.2030. This approach uses worst case assumptions such as no power control or antenna discrimination etc, which gives rise to somewhat pessimistic separation distances.

In the case of BS – BS interference (TDD into FDD) large separation distances or additional isolation is needed to mitigate interference effects, based on a macro to macro cell scenario using the minimum carrier separation of 5 MHz. This is due to the basic fact that downlink transmitters are spectrally close to sensitive uplink receivers. It should, however, be noted that practical equipment may have much better performance characteristics than the minimum values given in the specifications.

The effects of MS – MS interference are normally only noticed when the distance between MSs is very small, and there is a high probability of line-of-sight propagation. In addition, MS transmission power depends on its position in the cell and the load in the system. If the MS is close to its own BS then the effect will be smaller since the BS can increase downlink power to overcome the interference (assuming a margin is available). The deterministic approach used here does not take these factors into account and suggests that one MS could cause severe interference into another geographically and spectrally close MS. In reality, interference involving MSs is usually analysed using statistical analysis to look at capacity loss averaged over the system.

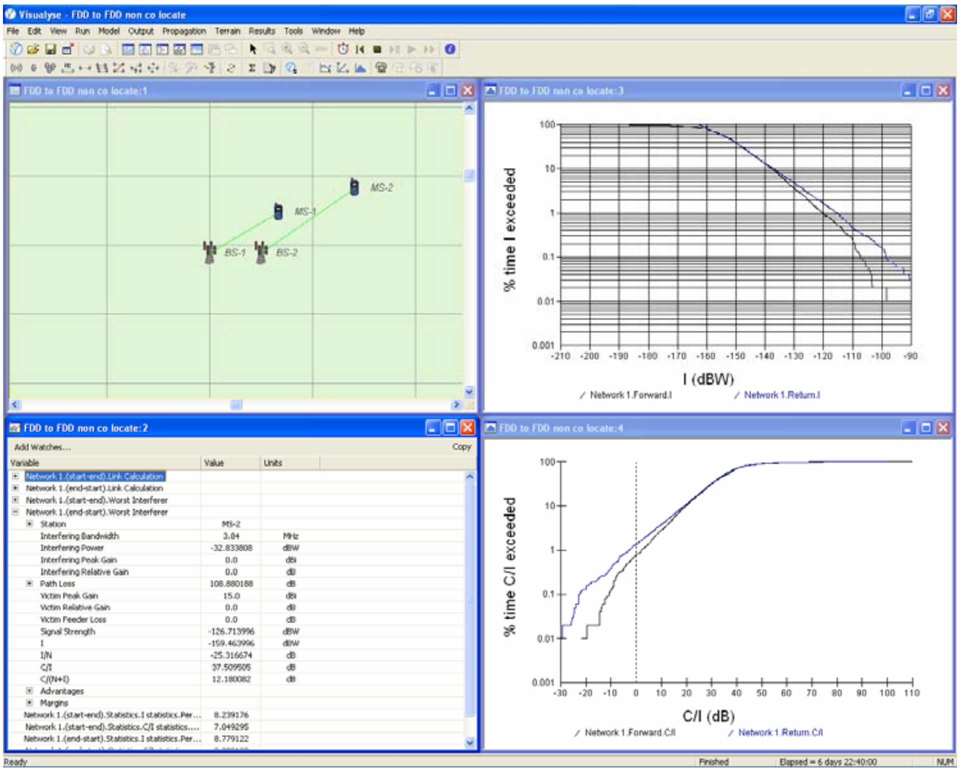
Therefore, although the deterministic approach is only really applicable to BS – BS scenarios, we have used it here to allow us to make a comparison of the “before” and “after” effect of a CoU from FDD to TDD operation.

It was noted that the fixed distance approach would suggest that even the FDD to FDD case would result in unacceptable levels of interference. However in practice there is not an interference issue. This is because the worst case conditions only occur infrequently and out of band masks are in general pessimistic. In general it is better to analyse these scenarios using Monte Carlo based techniques that can calculate the probabilities of interference. In the following section we consider BS – MS, MS – BS and MS – MS sharing using Monte Carlo simulations.

C.1.6 Monte Carlo Simulation

The scenarios above were repeated using a Monte Carlo methodology, making some simplifying assumptions where necessary. The location of the mobile was selected at random within a service area of size 2 km x 2 km. The propagation model was Hata (open), and power control was enabled for both the wanted and interfering links. The thresholds for interference were taken as -136 dBW or a C/I of 17 dB.

The figure below shows an example screenshot.



The following cases were considered:

1. BS of two networks co-located or separated by about 500m;
2. FDD as victim with interferer either FDD or TDD operating in the adjacent channel.

The results are shown in the table below.

Interferer TX	Victim RX	% time I exceeded	% time C/I exceeded
FDD-BS	FDD - MS	7.53	6.70
FDD-MS	FDD - BS	0.00	0.02
TDD-MS	FDD - MS	0.21	0.18
TDD-BS	FDD - BS	100.00	100.00

Table C-5: Results of Monte Carlo Simulation – Co-located

Interferer TX	Victim RX	% time I exceeded	% time C/I exceeded
FDD-BS	FDD - MS	7.32	6.32
FDD-MS	FDD - BS	1.57	5.19
TDD-MS	FDD - MS	0.19	0.16
TDD-BS	FDD - BS	87.13	95.01

Table C-6: Results of Monte Carlo Simulation – Non-Co-located

The following were noted:

- Analysis using C/I and I as the interference measure in general gave very similar results
- The results for both co-located and non-co-located were in this case similar
- Interference would be expected for a small but noticeable percentage of time between adjacent channel FDD systems if no guard band or other interference mitigation were used[9].
- Interference from TDD systems could cause significant long term interference into adjacent FDD systems in the BS-BS direction;
- Interference from TDD systems is unlikely to cause significant interference into adjacent FDD systems in the MS-MS direction;

C.1.7 Implications on Change of Use

From the results above the following conclusions were suggested;

- Operating in reverse direction i.e. introduction of TDD could cause unacceptable interference into the FDD network;
- The principle cause is that there is a fixed path between BS that could be extremely short (e.g. co-located BS) which together with the minimal ACIR for adjacent channels results in interference above any reasonable thresholds;
- Monte Carlo analysis proved more accurate in assessing interference as it can take account of the variations in parameters and derive probabilities of interference rather than just worst case;
- Using a fixed separation distance in the Minimum Coupling Loss method for interference analysis can lead to pessimistic results;
- It can be used to determine cases where there will not be any problems – for example use of very low EIRP devices;

[9] It is likely that more detailed analysis using actual system characteristics such as gain pattern, frequency plans etc would significantly reduce the percentage of time interference would occur.

- Analysis using Monte Carlo approach needed more details of a system than would be available at the SMR level.

C.1.8 Impact on SMR

Consider if the SMR is defined with the following envelope of parameters:

Parameter	Downlink band BS TX	Uplink band MS TX
Maximum EIRP (dBW)	28	-9
Required ACLR (dB)	45	46
Maximum antenna height (m)	30	1.5

Table C-7: SMR Envelope Parameters

In this case it would not be feasible to create SURs for the TDD network used in the previous simulations as it would not be consistent with the envelope of parameters in the SMR.

However it is worth considering what would occur if TDD BS were deployed with SURs based upon those for MS. Not only would the EIRP be significantly lower, but also the antenna height would be reduced at 1.5m.

These two parameters could be used to constrain deployment of TDD in FDD bands. Any TDD system that meets those limits would facilitate sharing as interference would be much less likely to occur – but it would significantly constrain development of TDD services.

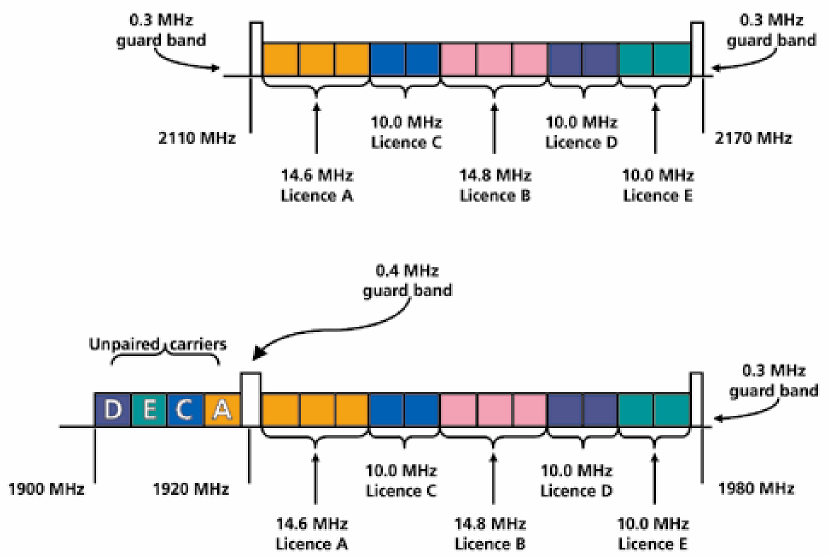
Interference would still occur if base stations were either co-located or separated by small distances, and this interference would occur continuously.

Any change to this envelope of SUR parameters would require negotiation with potentially affected parties.

D CASE STUDY: MOBILE OUT-OF-BAND

D.1 Background

This section describes some of the issues that could be raised by deployment of radio systems without central planning by the regulator. It considers a baseline scenario involving two mobile operators which operate in adjacent bands in similar geographic regions. Both are assumed to initially operate in the same direction (uplink vs. downlink) with similar technology (WCDMA – FDD). This would be consistent with usage in countries such as the UK where there is a channel plan as in the figure below.



For this baseline scenario, some of the changes that could be considered include:

1) Introduction of new base station using existing technology: could one be deployed at a specified location with defined characteristics without causing interference into sites of the other's network?

2) Could a change of technology (i.e. 2G to 3G or 3G to 4G) be permitted which would involve a change in the characteristics of the carrier transmitted without causing interference?

3) Significant increase in the number and hence density of base station deployment – does the aggregate interference result in serious degradation in adjacent bands?

4) Change in operation from FDD to TDD with reverse band working, causing BS to BS and MS to MS interference paths and adjacent frequencies (as discussed in a separate section);

5) Introduction of adaptive antennas resulting in increase in user densities and hence traffic levels;

6) Introduction and operation of fixed user terminal with higher gain antennas;
7) Change in service to higher power system providing more broadcast like services (e.g. DVB-H).
8) Change of technology to maximise throughput by transmitting at maximum EIRP permitted continuously

Note this section relates to OOB interference scenarios so it is assumed that all licences are national in extent.

In addition it is assumed that SURs are defined by EIRP not power so that the effect of transmit antenna peak gain need not be considered. It was assumed that at a minimum the SMR defined the following:

- Range of frequencies available for use
- Maximum peak EIRP and associated bandwidth
- EIRP mask in frequency to meet
- Maximum antenna height
- Type of station (fixed or mobile)

In order to do detailed interference analysis the following were also used:

- Cell size
- Number of co-frequency active mobiles
- Power control parameters
- Traffic and service profile
- Interference measure and thresholds
- Reference receive characteristics

Change 1: Deployment of new Base Station

Assuming FDD used in adjacent bands, then the following points can be noted:

1) Calculations based upon minimum coupling loss methods fails to take account of the variations within a CDMA network and hence results in extremely large distances which would suggest that deployment would fail.
2) Calculations based upon Monte Carlo analysis suggested that sharing would be feasible but required additional parameters to work.

It was therefore concluded that:

1) Additional information would be required to ensure deployment would not cause unacceptable interference
2) At present this includes knowledge of the application (i.e. typical 3G system parameters);

3) If this is not present then additional information or controls would be required.

Change 2: 2G to 3G

In this case the majority of the parameters are unchanged with the exception of the EIRP frequency mask. In theory this could be permitted without licence variation if the 3G service had EIRP frequency mask no higher than that for 2G. In addition the licence would have to define the mask in technology neutral terms (for example specifying power in reference bandwidth rather than defined via an ETSI standard).

However there are two potential problems:

1) In general as the 3G carrier is wider than that for 2G it decays slower in the frequency domain. However the 5 MHz channel plan is wider than the required 3.84 MHz giving some additional protection, lessening this effect;
2) Some 3G specifications have less stringent OOB characteristics than 2G, resulting in the need for additional attenuation or filtering even with use of a guard band.

One approach would be for operators to purchase equipment that is designed to a higher standard than that specified in documents such as the 3G standard 3GPP TS 25.104.

If the licensee wanted to change the mask then there would be a number of options:

1) negotiate directly with users of adjacent spectrum
2) gain approval by pre-determined system (such as automated coordination tool, minimum distance or OOB PFD % locations)
3) certify change would be ok (by analysis using database of available sites)

Change 3: Increase Density of Base Stations

In general there is a limit on the combination of EIRP and density due to system performance requirements. Hence if the density of BS increases, typically the individual EIRP decreases. However this might not necessarily be the case in the future. Therefore one of the following is required:

1) Knowledge and control of the application to be deployed;
2) Additional information or controls could be required such as using a sufficiently low EIRP that interference is very localised, or requiring that base stations submit to technical coordination, or that the operator meets an OOB PFD mask.

Change 4: Reverse direction from FDD to TDD

See detailed case study in Annex C.

Change 5: Increased density of mobiles

This could occur if each base station had more sectors allowing more re-use – potentially significantly more users if adaptive antennas are required. To first order, the impact is a linear increase in probability of interference in relation to the additional number of users. Therefore at some point there would be excessive interference. In this case one of the following would be required:

- The separation distance at which interference occurred would be so small as to permit user management of interference. This implies low power.
- There is knowledge and control of the systems being deployed to limit the user density;
- Additional information or controls.

Change 6: Use of higher gain fixed user terminals

Typically this brings advantages if the licence is specified in terms of maximum power as it can be used to increase the maximum permitted EIRP. In this case we are proposing there be limits on EIRP, so the benefit would be in terms of increased density of users.

This could cause problems due to two factors:

- Increased density of users increases the aggregate interference or probability of interference;
- Users would be operating as a fixed source of interference rather than a probabilistic one as with mobiles.

In this case as before either information about the application would be required or additional controls on interference.

Change 7: Use of higher EIRP base stations

This would require a change of SMR and so negotiation would be required with adjacent operators and with Ofcom to ensure the change is agreed as part of site clearance.

Change 8: Use of constant maximum transmit power

A fundamental part of 3G system engineering is the use of power control on both the uplink (mobile transmit) and downlink (base station transmit) directions. Therefore the maximum EIRP defined in the SMR would only be used infrequently. However it could be argued that the operator could be permitted to operate their equipment at maximum EIRP all the time while remaining within their legal rights. This could have operational benefits (higher data rates would be feasible using adaptive coding methods), but resulting in interference implications.

Based upon parameters for the TDD-FDD scenario, interference between FDD downlinks would rise to over 30% of the time should power control not be used on one link. This would represent a significant degradation, but would be permitted under the envelope of SMR parameters.

Therefore additional controls could be required.

D.2 Use of OOB PFD for X% of locations

One possible approach to manage out-of-band interference is the use of aggregate OOB PFD not exceeded for X% of locations. This approach would have the benefits that:

- It would give a good idea of the level of interference that operators in adjacent bands could experience;
- It would give operators a good idea about how they could deploy their network flexibly without causing interference;
- It would not be possible to dramatically increase density of either BS or MS without reduction of EIRP or use of filtering as that would result in linear increase in percentage of locations interfered;
- It would not be possible to switch off power control without either reducing EIRPs or entering into negotiations.

This section considers implications of OOB PFD masks for the 3G example above. For a range of cells sizes the OOB PFD mask was derived using the following stages:

1) Derive the PFD threshold based upon receiver interference thresholds. These are calculated assuming single entry cases: there would also be aggregation of carriers (users) and aggregation of base stations. However these give an indicative feel of the scale of the PFD % locations assuming the OOB PFD threshold is based upon the interference threshold of -136 dBW = -106 dBm which corresponds to a PFD at 2 GHz of -116.8 dBW/m^2/5 MHz or -123.8 dBW/m^2/MHz.
2) Calculate the distance from the transmitter needed at which this PFD level is just reached given the mean EIRP, the OOB attenuation factor or ACLR, and a propagation model. In this case the Hata model was used for urban environments, with parameters as in the table below. Note that the Hata model gives the median loss, so the result is appropriate for the 50% of time statistic and the EIRP was taken as the mean assuming power control activated.
3) From the distance required to meet the PFD, the area excluded per transmitter was calculated using πR^2. Then an assumed maximum number of transmitters within a unit area of 1 km^2 was used to calculate the total area over which the PFD would be exceeded. This was based on a cell having a maximum of 12 simultaneously active users.

The result of the calculation is a figure for the percentage of locations that the PFD threshold is exceeded, that allows an OOB PFD mask to be defined in the format:

> *The OOB PFD at any point up to 20 m above ground level should not exceed -123.8 dBW/m^2/MHz for more than 50% of the time at more than X % of locations in any km^2*

Direction	BS TX	MS TX	BS TX	MS TX	BS TX	MS TX
Cell radius (km)	2	2	1	1	0.5	0.5
EIRP (dBW)	15.7	-9	5	-13.9	-5.4	-24.3
I target (dBW)	-136	-136	-136	-136	-136	-136
ACLR (dB)	45	33	45	33	45	33
Loss required (dB)	106.7	94	96	89.1	85.6	78.7
Hata slope	3.52	4.37	3.52	4.37	3.52	4.37
Hata constant (dB)	137.4	155.4	137.4	155.4	137.4	155.4
Distance (m)	134.2	39.35	66.7	30.40	33.8	17.57
Area (% of km^2) per transmitter	1.415	0.122	1.396	0.290	1.432	0.388
No. of transmitters per km^2	1	3	1	12	4	48
Total Area (% of km^2)	1.415	0.365	1.396	3.483	5.729	18.627

Table D-1: Area of cell covered for which OOB PFD threshold would be exceeded

It should be noted that these figures were derived based upon simplistic assumptions and any real data could be very different. In particular a very basic propagation model was employed and the interference only from a single user considered with limited system details.

The following were noted:

1) There was significant differences between the results for different cells sizes – for example the MS TX case the area excluded varied from 0.36 % to 18.6 %;
2) The BS TX case was worse than MS TX for large cells while the MS TX case was worse than the BS TX case for small cells;
3) The results are highly dependent upon assumptions about system characteristics such as transmit EIRP, use of power control, and density, and environment issues such as propagation models.

The OOB PFD for % location does not say where interference occurs, so there could be problems if base stations are co-located. However in this case there should be negotiation with the tower owner that should cover issues such as direction of operation.

More detailed analysis using more Monte Carlo techniques could be used to derive OOB PFD masks more representative for systems such as 3G.

E AGGREGATION OF BR CHANNELS TO DAB

E.1 Description of Scenario

The baseline for the scenario was the 450 MHz band populated with a number of wide area Business Radio (BR) networks. These provide voice communication services to private organisation, for example taxi or bus companies. The networks will have been planned so that they can operate using the parameters in their licences without causing or suffering interference from other licensed users.

An operator purchases a number of BR licences in the London area with contiguous spectrum and aggregates their narrow bandwidths to provide a wider band service, in this case Terrestrial Digital Audio Broadcasting or DAB. The key parameters are shown in the table below.

BR bandwidth	25 KHz
DAB bandwidth	1.536 MHz
Number of BR carriers aggregated	62

Table 8: Scenario Key Parameters

Rather than modelling all 62 bands, together with all BR networks in each, the following two typical networks were used to model in-band and out-of-band effects:

- BR typical co-located licence = Clapham
- BR typical co-frequency licence = Oxford

All analysis was undertaken using Visualyse Professional version 5.

E.2 System Parameters

This section defines the technical characteristics assumed for the interference analysis. It should be noted that while these were considered as representative for the systems under consideration, there is a wide range of types of networks and hence the parameters for some actual systems are likely be different.

The frequency band selected was UHF 2, using a frequency of 460 MHz. The propagation model used was ITU-R Rec.P.1546-1 with the SRTM terrain database. No consideration was made as to receiver filter characteristics due to lack of suitable specifications.

The key system parameters are given below based upon standard documents including Ofcom TFACs and other recognised sources such as ECC Reports, ETSI standards etc.

These parameters were then mapped to a technological neutral set, for example based upon EIRP and bandwidths. No difficulties were encountered in this process apart from the issues relating to the technology specific thresholds used to assess the ability of BR systems to share spectrum. The current planning process determines compatibility by combining C/I levels and probabilities of blocking to provide a measure of the grade of service. This would not be applicable to other services and so does not represents a technological neutral measure of spectrum quality.

Compatibility measures can be defined in a number of ways – from complex (such as C/N+I and C/I) to more basic (such as I/N or interference in receiver bandwidth). A decision was therefore required as to what measure of spectrum quality should be used, taking into account:

- the need for technology neutrality;
- the need to be able to used to assess compatibility between all types of radio systems;
- the need to assess the quality of spectrum from a radio users perspective;
- the ability to be a measure than can be calculated in interference simulations;
- the need to be computable within reasonable timescales.

It was decided that a suitable format of the technology neutral interference threshold to be used as the IIL would be:

> *Interference at the receiver should not exceed X dBW for more than Y% of time at no more than Z% of locations.*

This can be derived from the C/I thresholds and the minimum wanted signal level, as described below.

It is noted the evaluation of the performance of business radio networks can use the quality of service measure “call blocking”. This takes account of the shared nature of their use of the radio spectrum via the probability that a request to communicate is blocked by another user’s call. However this measure is not applicable to all services and so can not be considered a generic technologically neutral measure of spectrum quality.

However elements of the blocking probability can be incorporated in the IIL above, as it would change the Y% of time to a higher value. Furthermore the interference threshold could be adapted to take account of other system characteristics.

Using a threshold based upon interference level rather than C/I could be considered more conservative, as higher levels of interference might be otherwise be permitted in regions of the licence where the wanted signal exceeds the minimum level. Detailed analysis could also use Monte Carlo techniques to convolve propagation time variation with traffic activity factors when using an IIL in the format above.

It is therefore suggested that it is likely to be acceptable to use this technological neutral definition of spectrum quality.

E.2.1 BR Systems

The parameters for BR systems were taken from the following documents:

- Ofcom TFAC OFW 164
- Ofcom IR 2044
- ETSI EN 300 113 & EN 300 086
- CEPT Recommendation T/R 25-08

Channel Spacing	25 kHz
Type	Wide Area Voice
Direction	Base Station TX, Mobile Station RX
ITU-R Rec. P.1546 availability requirement (wanted)	50% of locations for 50% of the time
ITU-R Rec. P.1546 availability requirement (interfering)	50% of locations for 10% of the time
C/I Requirement	12 dB
Receiver Minimum Sensitivity	-104 dBm (-134 dBW)
Interference level (derived)	-116 dBm (-146 dBW)
Transmit power (ERP)	15 W
Transmit gain pattern	Isotropic 0 dBi
Transmit antenna height	15m
Receive gain pattern	Isotropic 0 dBi
Receive antenna height	2m

Table C.1.1: BR General Radio Characteristics

A number of example systems were generated for comparison:

Name	Latitude	Longitude
Clapham	51.45N	0.22W
Oxford	51.40N	1.32W

Table C.1.2: BR BS Locations

A service area was constructed within which the wanted signal was at least -104 dBm. A plot of the coverage of the Clapham and Oxford networks together with the service areas are shown below.

Key to Figures

In this section the following applies to all figures:

- A polygon of straight lines connecting a set of points represents the system's service area which should be protected from interference;
- Irregularly curved line: predicted coverage of wanted signal of proposed service.

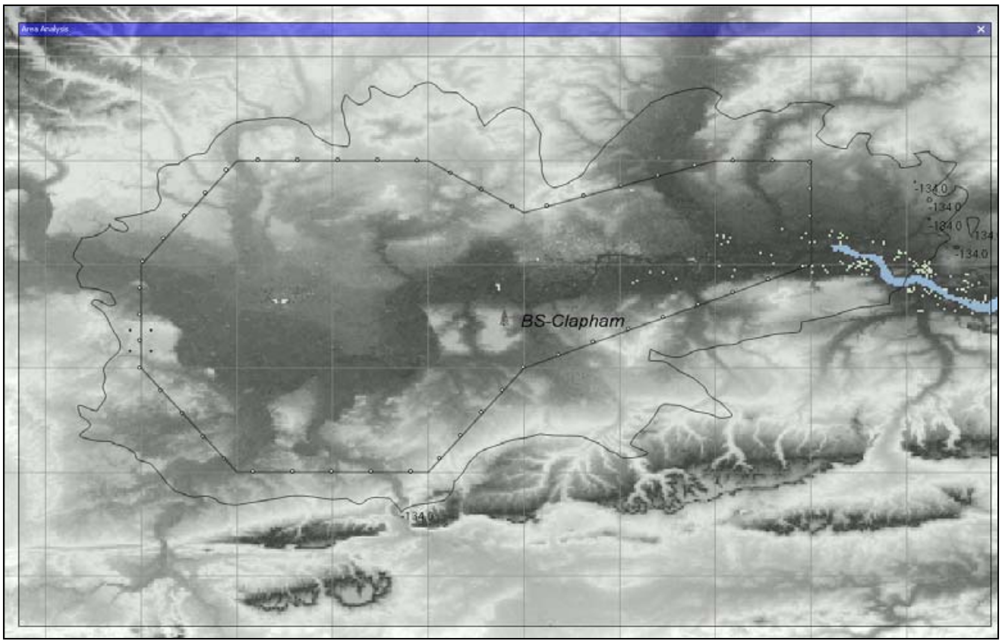


Figure C.1.1: Clapham BR coverage and service area

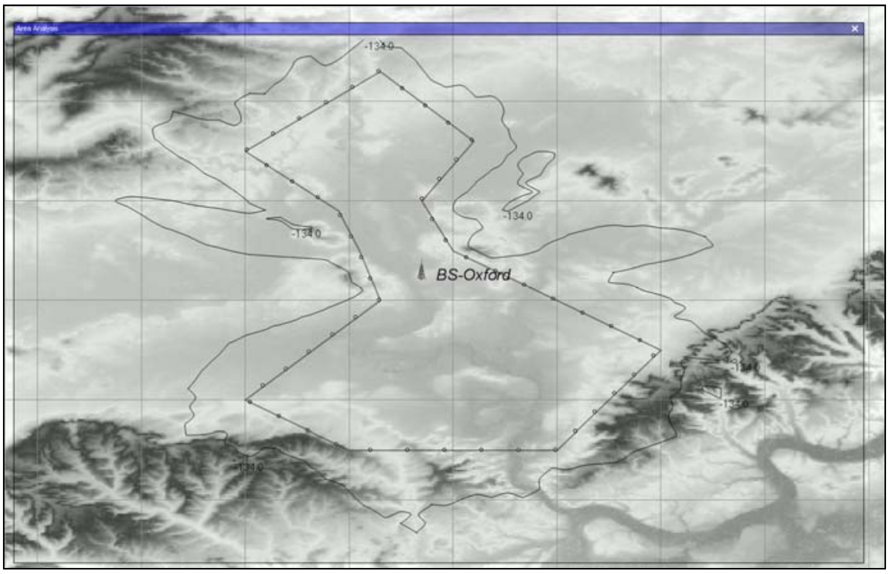


Figure C.1.2: Oxford BR coverage and service area

To ensure compatibility, the interference generated by each along the others boundary was computed, and the worst values were as in the table below.

Clapham into Oxford	-146.1 dBW
Oxford into Clapham	-146.4 dBW

Table C.1.3: BR to BR Interference Levels

It can be seen that in both cases the highest interference levels are just below the thresholds of –146 dBW.

The adjacent channel power density was taken as 70 dB below the in-band power, hence it would be a transmit power of –58.2 dBW in every 25 kHz.

E.2.2 DAB System

The parameters for the DAB systems were taken from the following documents:

- ECC Report 49: Technical Criteria of DVB-T and DAB Allotment Planning, Annex 4
- Final Acts of the CEPT DAB Planning Meeting, Maastricht 2002
- ETSI EN 302 077-2: Electromagnetic compatibility and Radio spectrum Matters (ERM); Transmitting equipment for the Terrestrial - Digital Audio Broadcasting (DAB) service; Part 2: Harmonized EN under article 3.2 of the R&TTE Directive

Channel Spacing	1.536 MHz
ITU-R Rec. P.1546 availability requirements (wanted)	95% of locations for 50% of the time
ITU-R Rec. P.1546 availability requirements (interfering)	50% of locations for 1% of the time
ITU-R Rec. P.1546 k factor class	Broadcasting - Digital
C/N Requirement	15.0 dB
Receiver Noise	-135.1 dBW
Margin for interference	3 dB
Aggregate interference level (derived)	-135.1 dBW
Noise plus interference (derived)	-132.1 dBW
Minimum Wanted Signal (derived)	-117.1 dBW
C/I level (noting that propagation variation is including in Rec. 1546)	10.0 dB
Interference threshold (assuming propagation model run using 1% of time)	-127.1 dBW
Transmit power	29.7 dBW
Transmit gain pattern	Isotropic 0 dBi
Transmit antenna height	150m
Receiver Antenna	Isotropic 0 dBi
Receiver antenna height	1.5m

Additional losses (e.g. building penetration)	12 dB

Table C.1.4: DAB General Radio Characteristics

Name	Latitude	Longitude
Crystal Palace	51.424N	0.075W

Table C.1.5: DAB Transmitter Location

As the bandwidth of DAB is significantly larger than for BR, the power can be corresponding higher without changing the spectral power density. For example 10log10(1.536MHz / 25kHz) = 17.9 dB. So the DAB network can transmit at up to 11.8 + 17.9 = 29.7 dBW while retaining the same power density as BR. In practice there will be other constraints – for example the need to remain within plans agreed on an international basis plus any national plan for broadcasting spectrum. However this figure is within the ranges defined in Annex 4 of ECC Report 49.

A plot of the coverage of the DAB network together with service area for planning purposes is shown below.

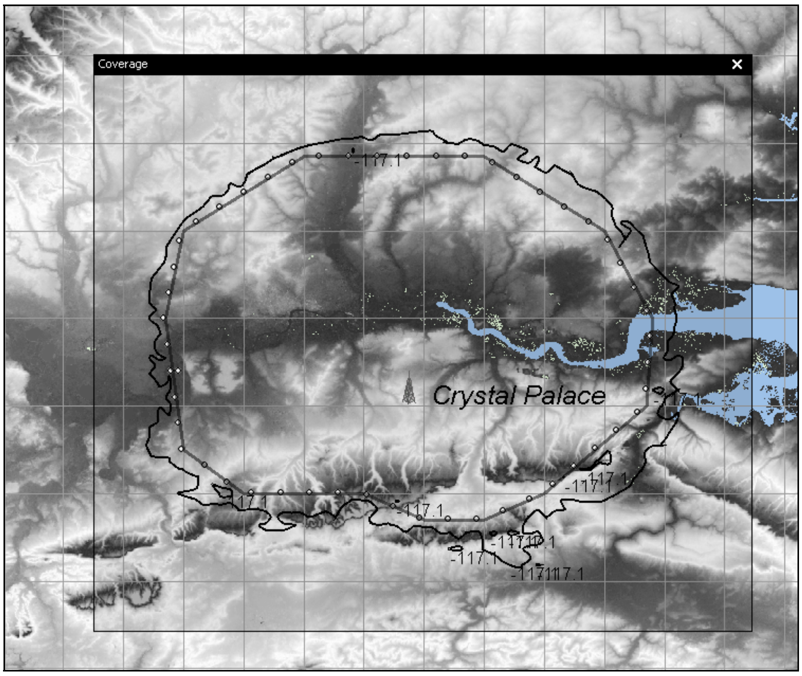


Figure C.1.3: Example DAB Coverage

The OOB emission mask used was taken case as Case 1: VHF DAB transmitters operating in critical cases from ETSI EN 302 077-2 as in the table below.

Frequency offset(MHz)	Ratio of OOB power to in-band power density
0.77 MHz	0 dB
0.97 MHz	- 71 dB
1.75 MHz	-106 dB
3 MHz	-105 dB

Table C.1.6: DAB OOB Mask

As the in-band power is 29.7 dBW in 1.536 MHz with attenuation of 71 dB the OOB power would be –59.2 dBW in a BR 25 kHz bandwidth operating in an adjacent band.

E.3 Sharing Analysis

Replacing the London BR networks by DAB created the following interference paths:

In-band paths:

- From Crystal Palace DAB into Oxford BR;
- From Oxford BR into Crystal Palace DAB.

Out-of-band paths:

- From Crystal Palace DAB into Clapham BR;
- From Clapham BR into Crystal Palace DAB.

These are described further in the sections below.

E.3.1 From Crystal Palace DAB into Oxford BR (in-band)

The interference scenario is shown in the figure below, which also shows the most sensitive point on the BR service area where the interference reached -136.5 dBW.

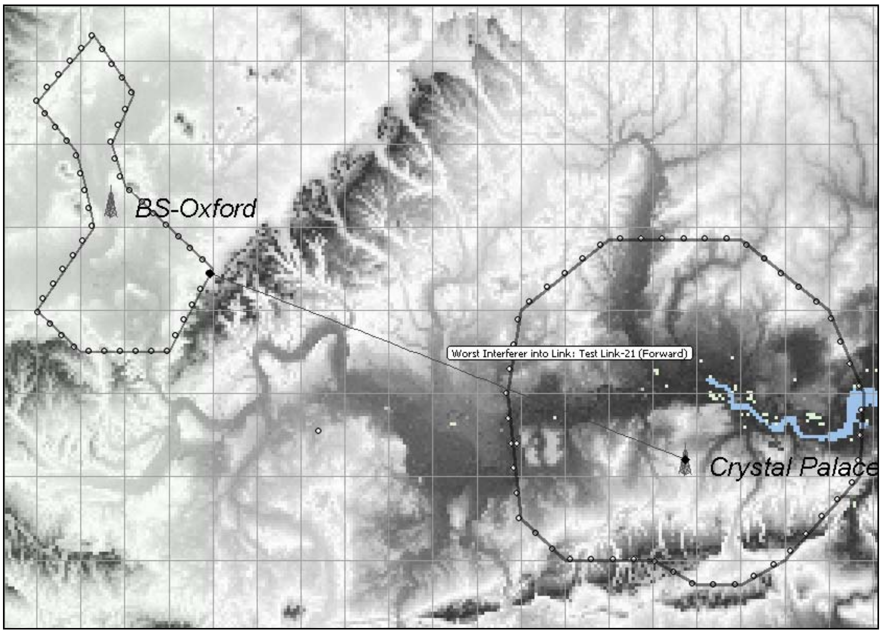


Figure 6: TDAB to BR Oxford Interference scenario

The interference threshold was set at –146 dBW, and therefore the DAB would be 9.5 dB above the level required, despite the fact that the EIRP density had not changed from that used by the London template BR network at Clapham. The principle reason for the increase in interference was effect of the transmitter height i.e. 150m rather than 15m.

This highlights an important aspect to analysis between radio systems: there can be subtle non-linear effects of varying some of the SUR parameters. For example as height increases, interference can decrease (the transmitter is physically further away) or increase (as the transmitter is now clear of surrounding clutter or terrain). If a SUR owner proposes to increase their antenna height but decrease the EIRP what will the overall effect be on adjacent licences?

Without undertaking interference analysis it is hard if not impossible to predict the impact of the proposed change. And for interference analysis to be used to determine whether CoU between SUR owners can be permitted there must be a threshold to compare against. This implies there is a need for an indicative interference level.

E.3.2 From Oxford BR into Crystal Palace DAB (in-band)

The figure below shows the point where the interference was highest, namely –163.8 dBW. It can be seen that this is below the IIL defined for this DAB network.

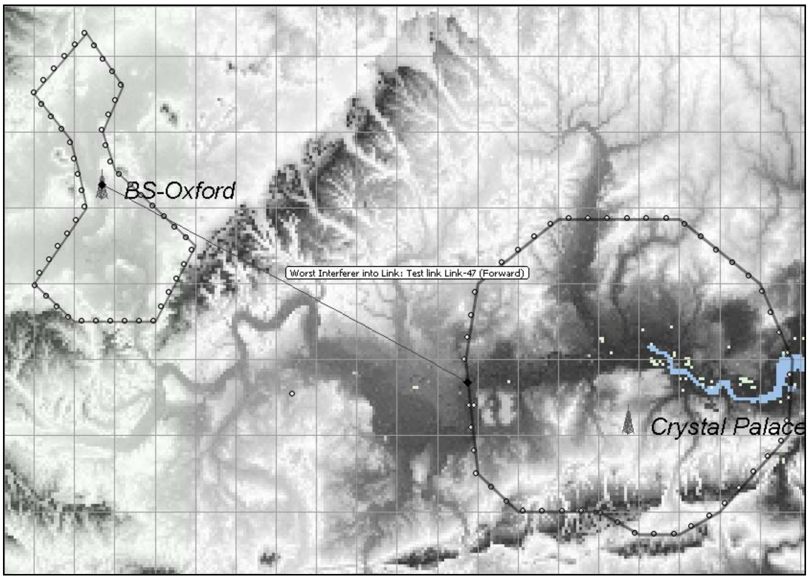


Figure 8: Worst Interfering Path from Oxford BR into DAB network

The interference level is below that of the corresponding Oxford BR into Clapham BR because:

- The service area is further away, increasing the path loss;
- The receiver is assumed to be indoors, so there are additional building penetration losses.

This scenario raises a number of issues relating to the use of IILs as discussed below.

Whether to check interference *into* the CoU Licence

The standard issue when considering CoU is to ensure that the new licence configuration would not cause interference into the receivers of other licences. However there is benefit in undertaking additional checks to ensure the altered licence will not suffer interference from other licences, and not just for that licensee's operational benefit.

One of the fundamental requirements of any regulatory regime that permits liberalisation is that any CoU should not harm the rights of existing licensees to operate as defined in their licence. Therefore emission rights and receive IILs should remain consistent after a CoU

Should a licensee request a CoU to an extremely stringent IIL and it is approved by the regulator without checks, there is the danger that it will not be consistent with the emission rights of other licences. Any CoU in any of these other licenses could be rejected for being inconsistent with the stringent IIL - even if they are identical to existing transmit levels. An example of the problems this could create is described in section 4.5.1.

Therefore if there are any changes to a licence's receive characteristics, including the IIL, there are significant benefits in ensuring the regulatory regime checks to ensure these are consistent with the existing emission rights of other licenses.

Aggregation and IILs

The aggregation of multiple BR networks to create a single DAB network alters the receive characteristics in one critical way: the DAB receiver bandwidth is significantly larger than that for each BR receiver.

Therefore while the interference levels it can tolerate over the larger bandwidth are significantly higher, the number of sources of interference has also significantly increased.

Consider the BR interference threshold of –146 dBW within the receiver bandwidth of 25 KHz. If the CoU system uses a bandwidth of 1.5 MHz, then the interference threshold could be 60 times higher, namely –128.2 dBW. However there will be 60 times as many sources of interference. This problem is shown in the figures below.

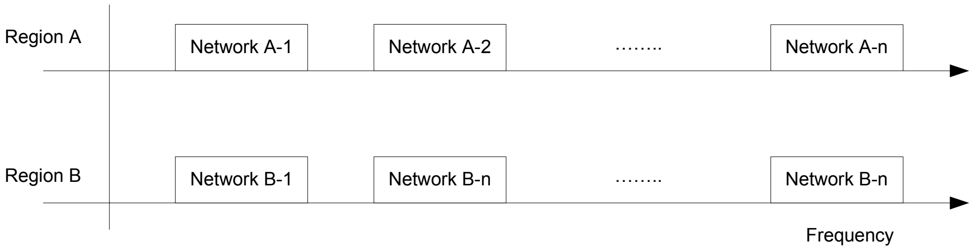


Figure 9: "AsIs" Multiple narrow-band networks in both Regions A and B

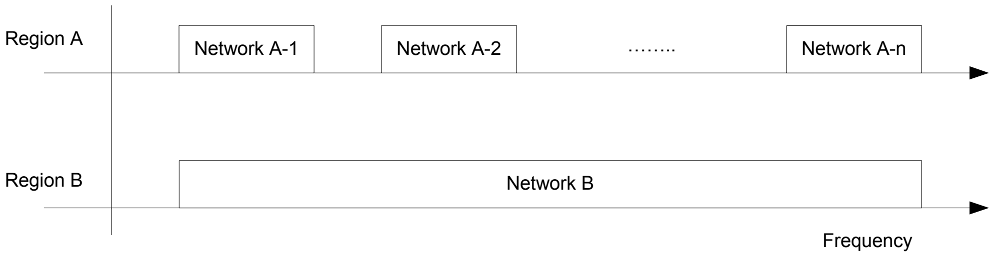


Figure 10: "ToBe" One region switches to a single wide-band network

Therefore if the IIL is changed to –128.2 dBW, then there would be the danger that each of the narrow band networks could be allowed to increase their transmit power by 17.8 dB. The result would be the aggregate interference into Network B would exceed the levels at which it could provide the required quality of service.

An additional issue is what to do to the thresholds should some of the Region A licences merge, as in the figure below.

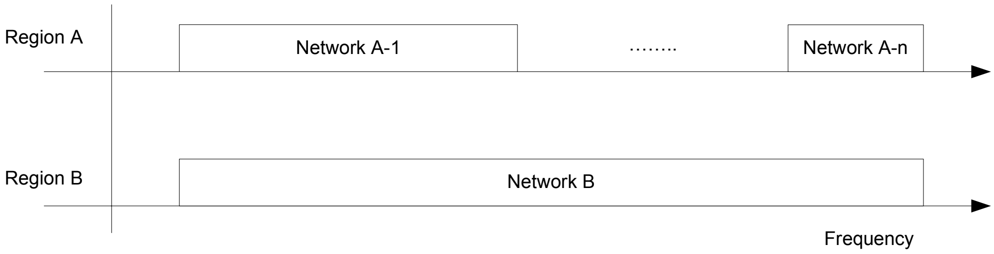


Figure 11: “ToBe” Changes in both Region A and B

In this case Network A-1 and A-2 merge: the in-band interference allowance from the two into Network B should therefore be doubled.

An additional issue is that the “AsIs” scenario could involve multiple types of network, each with their own definition of IIL, as in the figure below.

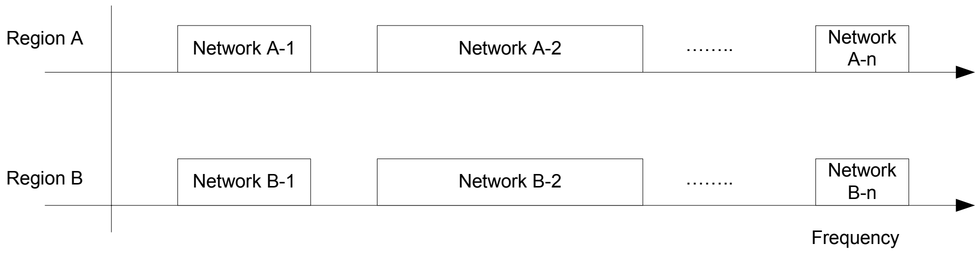


Figure 12: “AsIs” Different bandwidth networks in both Regions A and B

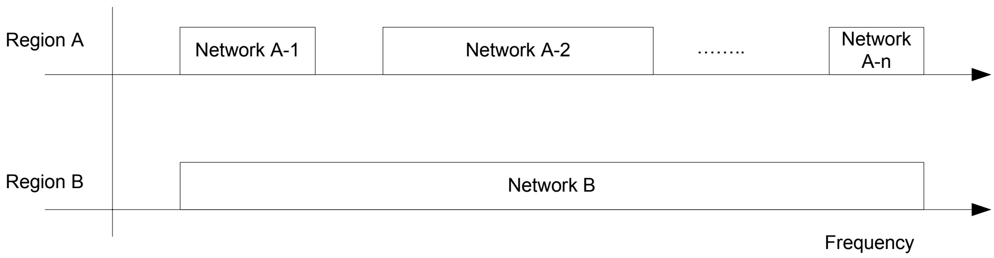


Figure 13: “ToBe” One region switches to a single wide-band network

There are a number of possible options to resolve this problem:

1) Keep all or some of the existing licence receive characteristics – e.g. same service area and bandwidths (assuming that the receive bandwidth / filter characteristics are only used for interference assessments and are not a requirement for receivers to meet);

2) Use the new licence characteristics but set the interference threshold low to take account of the increased number of sources of interference (effectively change the aggregate to single entry interference apportionment rule).

3) Employ a scaling factor to calculate the single entry IIL. A possible scaling factor could be the ratio of the frequency overlap: so if the victim network is 60 times the bandwidth then each would only be permitted a 60th of the IIL of the total interference.

Similar problems of determining suitable IILs occur if aggregating licences geographically, as in the figure below.

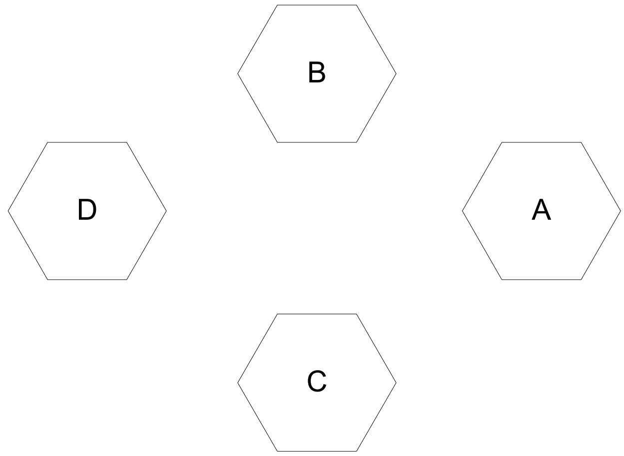


Figure 14: "AsIs" Co-frequency networks A,B,C,D

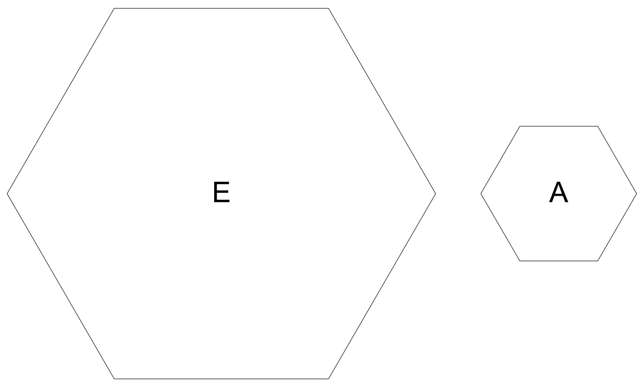


Figure 15: "ToBe" Networks B,C,D aggregated to E, A unchanged

In this example an operator purchases licences B,C, and D and aggregates them to provide a single service, E. The question is then what is the interference allowance from E into (unchanged) licence A? While it would be appropriate to have some increase to take account of B and C being adjacent to A, it could be argued that D, further away, should not bring additional interference benefits.

The method used should also be applicable to scenarios where licences are split in frequency or geography. It should also encourage parameters in the licence to reflect the actual spectrum usage, rather than keeping with historical values which might not reflect the most efficient use of spectrum.

E.3.3 From Crystal Palace DAB into Clapham BR (OOB)

The figure below shows the sharing scenario from the Crystal Palace DAB into the Clapham area BR network. It can be seen that the transmitter was not within the service area of the BR network: there was therefore some geographic as well as frequency separation.

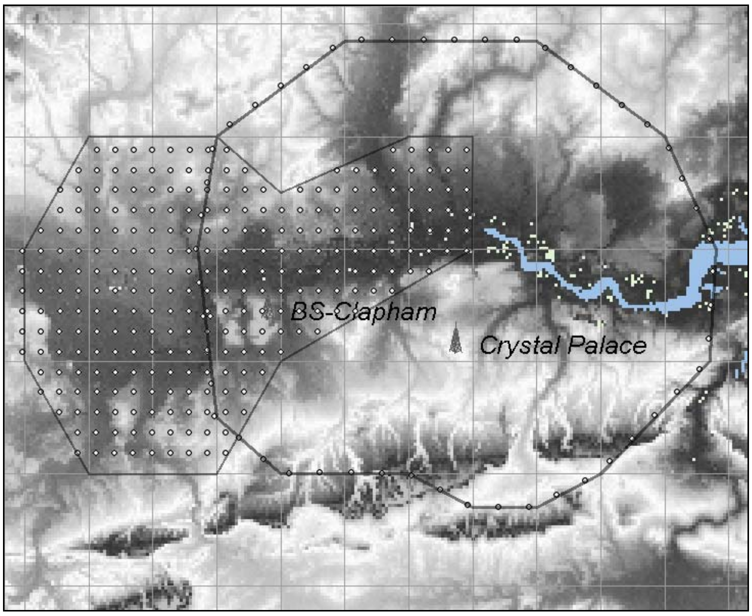


Figure 16: OOB Sharing Scenario

The worst interference level was –161.7 dBW, well below the IIL of –146 dBW. This assumes that the same threshold is used for OOB cases as in-band: it could be the case that lower levels of interference are permitted from non-co-frequency sources.

To simulate a co-frequency co-located deployment the DAB transmitter was moved to be within the service area of the Clapham BR network. In this case the worst case interference detected was –145.2 dBW, just above the IIL. The distribution of interference across the service area was as shown in the CDF below.

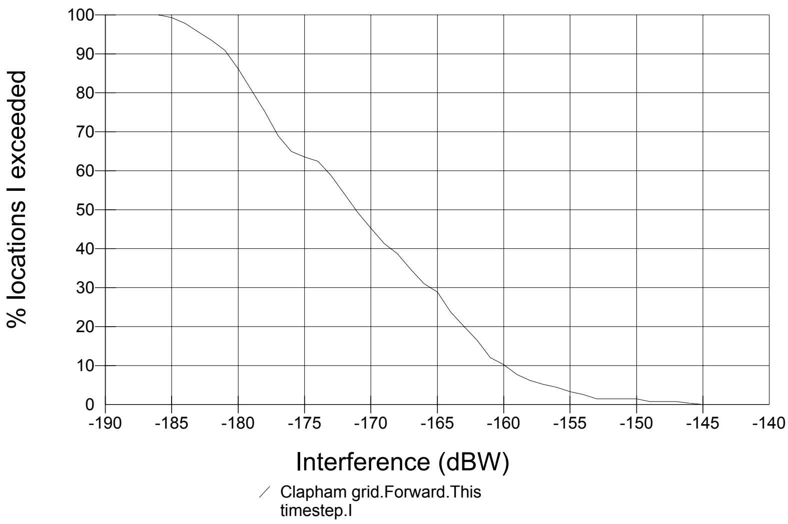


Figure 17: CDF of OOB interference from DAB into BR

This is to be expected as with a threshold of –146 dBW and transmitter power of –59.2 dBW in 25 kHz interference will occur within about 1.1km of the interfering station (assuming free space path loss).

However it should be noted that the IIL format involves a term covering % locations and therefore it is likely that this would be acceptable as only a small percentage would be effected. For example if the denied area has radius 1.1 km then the percentage of locations over a typical 30 km radius BR network that is unavailable is only 0.1%. As BR networks typically have availability requirements in the order of 90 – 95% of locations this unavailability would be acceptable.

It should be noted that under present Ofcom procedures there is an acceptance that there could be interference between adjacent channel BR networks if the base stations are very close in both frequency and geography. For this reason Ofcom states in TFAC OFW 146:

> "A proposed system will not normally be assigned in the first-adjacent channel of an existing system that is within 500m of the proposed antenna site".

E.3.4 From Clapham BR into Crystal Palace DAB (OOB)

The figure below shows how the Clapham BR transmitter is located within the DAB service area and therefore represents a co-located adjacent band source of interference.

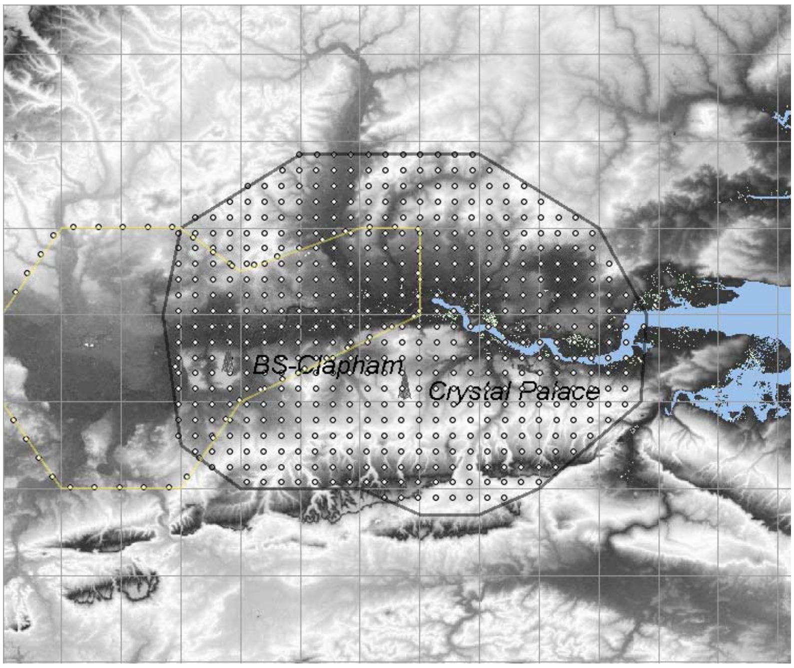


Figure 18: DAB into BR OOB scenario

As the networks are co-located, it is inevitable that in some locations any reasonably threshold would be exceeded, if only for small percentages of locations. The figure below shows the CDF of interference across the service area:

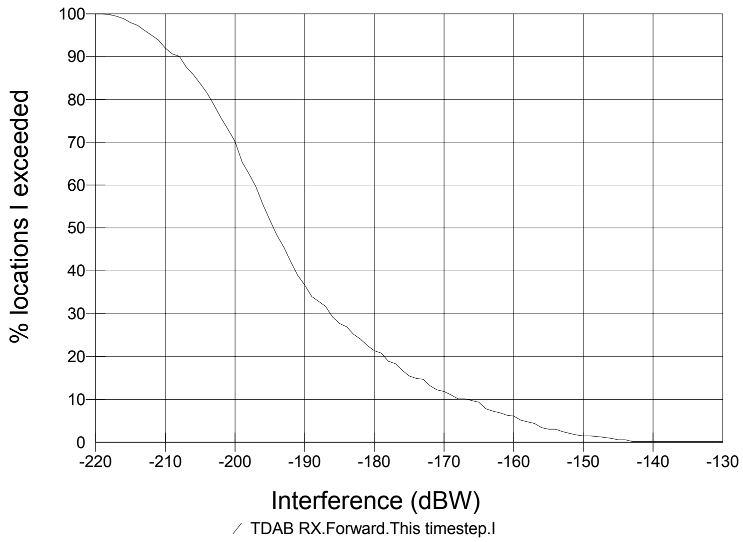


Figure 19: CDF of OOB interference from BR into DAB

Note that this is the interference into the DAB receiver bandwidth of 1.536 MHz.

It can be seen that the interference is low for the majority of DAB receiver sites and therefore this interference path wouldn't be problematic unless the interference threshold was very stringent.

An issue does remain about what threshold to use as:

- the interference is from an adjacent band, not co-frequency
- the bandwidth of the BR system is significantly less than that for DAB and therefore it could be appropriate to apportion interference assuming more BR networks contribute
- the BR network does not fully overlap in geography the DAB network: this could be an argument to either decrease its interference allowance or to increase it.

E.4 Procedural Issues

It can be seen that a large number of BR licences would have to be purchased to allow aggregation of spectrum to provide DAB services. This could be costly and there could be problems of hold-out by a few users.

In addition the methodology to define IILs needs to be explicitly defined, taking into account issues such as:

- Single entry limits vs. aggregate;
- Partial overlap in frequency;
- Aggregation of licences;
- Splitting of licences;
- In-band vs. out-of-band thresholds.

E.5 Conclusions

In order for this change to be allowed under a SUR regime, the DAB network licence holder would need to undertake at least one of the following steps:

1) Gain agreement from the BR radio operator that it would accept higher levels of interference (however note that the –146 dBW threshold would be exceeded over all of the Oxford BR operator's service area);

2) Purchase additional BR licences over a wider area;

3) Reduce the transmit power and reduce the service provided either by increase coding and/or reduce modulation, resulting in reduced payload (i.e. lower data rate services or fewer channels) or accept lower QoS to users (i.e. reduced ability to serve indoor users without a fixed antenna);

4) Reduce the transmit power and accept the corresponding decrease in service area. The coverage using a 20 dBW transmitter is shown below compared to the old service area.

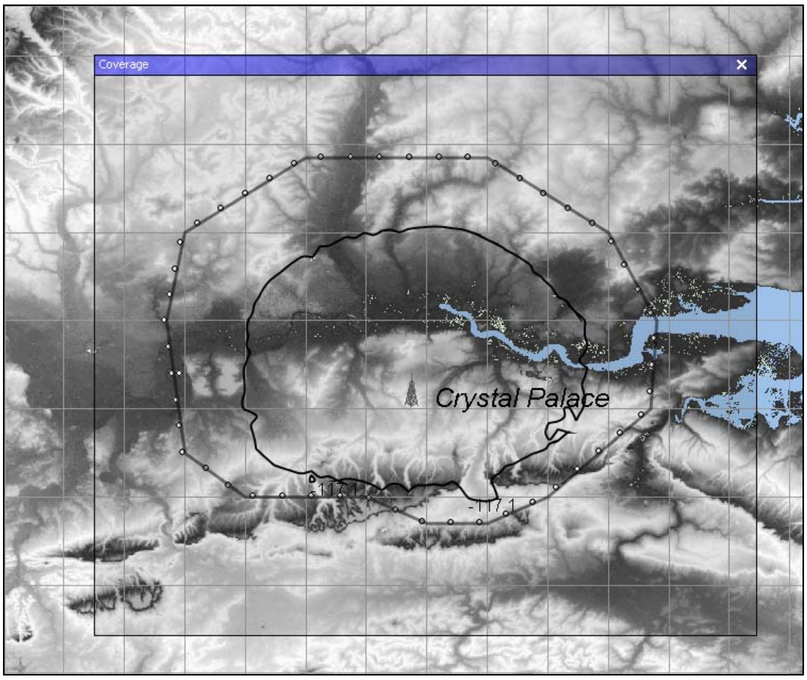


Figure 7: DAB Coverage with 20 dBW EIRP transmitter

F FS LINK CHANGED TO MOBILE NETWORK

F.1 Description of Scenario

This scenario start with the “AsIs” scenario of the 1350 – 1375 MHz / 1492 – 1517 MHz bands populated with FS networks. For simplicity only two links are modelled in the London / Thames valley region, as in the figure below.

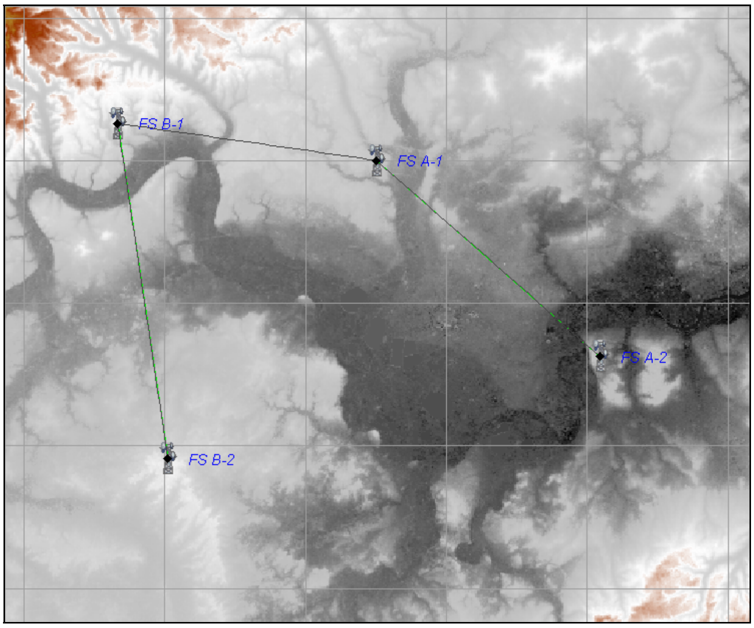


Figure 20: Scenario “AsIs” with two FS networks

Each FS link is bi-directional and has parameters consistent with the requirements of TFAC OFW 46 (version 1.1). The two directions are described as “forward” and “return”.

The FS link operating closest to central London is assumed to request change of use to a mobile network. The frequency used in one FS direction used for the mobile uplink and the other for the mobile downlink.

This mobile network has then to ensure that the remaining FS link is protected i.e. interference is below the level in its IIL. The new scenario is shown in the figure below.

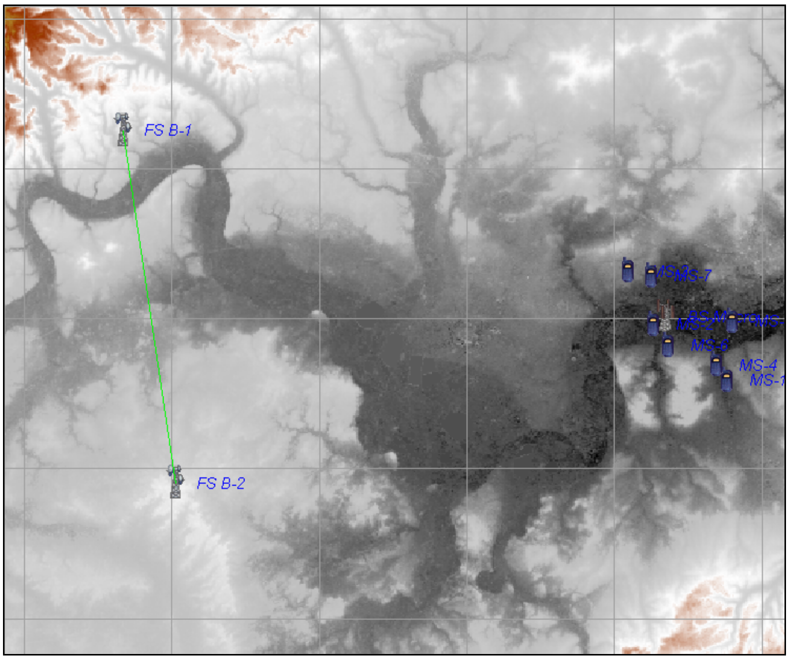


Figure 21: Scenario "ToBe" with FS network and mobile network

Note: this section describes a CoU scenario defined as a test case in the GRMT project. The results were generated by GRMT software and cross-checked where feasible against Visualyse Professional Version 5.

F.2 Parameters

These parameters were then mapped to a technological neutral set, for example based upon EIRP and bandwidths. No difficulties were encountered in this process. The propagation model used was ITU-R Rec. 452 unless otherwise stated.

The FS key parameters are given in the table below:

Direction	Forward	Return
Frequency	1.5 GHz	1.35 GHz
Bandwidth	1 MHz	1 MHz

Table 9: FS Key Parameters

The Mobile Network key parameters are given in the table below:

Direction	Downlink	Uplink
Frequency	1.5 GHz	1.35 GHz
Bandwidth	3.84 MHz	3.84 MHz

Table 10: Mobile Network Key Parameters

Note that this section uses the following terms to describe the mobile network:

Downlink: from the base station to mobile handset

Uplink: from the mobile handset to the base station

The frequency band selected was L band using frequencies of 1 350 MHz paired with 1 500 MHz. The propagation models used were ITU-R Rec.P.452-11 and P.1546-1 with the SRTM / OS terrain databases. As this scenario only involved in-band paths, the transmit EIRP and receive filter masks are not required.

F.2.1 FS Network A

The table below defines the parameters of FS Network A (which is to be changed to a mobile network). The principle source of information was the Ofcom TFAC OFW 46 version 1.1. The parameters of this link were checked to ensure that the performance objectives of an unavailability due to propagation of no more than 0.01% would be met.

Licence	**FS-A**	**FS-A**	**FS-A**	**FS-A**
Direction	**Forward**	**Forward**	**Return**	**Return**
Type	**TX**	**RX**	**TX**	**RX**
Location type	Point	Point	Point	Point
Antenna height (m)	20	20	20	20
Antenna pointing	at target	at target	at target	at target
Antenna pointing at	FS-A1 RX	FS-A1 TX	FS-A2 RX	FS-A2 TX
Antenna gain pattern	Rec.F.699-6	Rec.F.699-6	Rec.F.699-6	Rec.F.699-6
Peak gain (dBi)	30	30	30	30
Beamwidth (deg)	5	5	5	5
Transmit power (dBW)	-38.3	n/a	-40.5	n/a
Centre Frequency (GHz)	1.5	1.5	1.35	1.35
Occupied Bandwidth (MHz)	1	1	1	1
Allocated Bandwidth (MHz)	1	1	1	1
Polarisation	LinHor	LinHor	LinHor	LinHor
IIL-1 % locations	n/a	0	n/a	0
IIL-1 % time	n/a	0.01	n/a	0.01
IIL-1 Interference (dBW/RX BW)	n/a	-128.9	n/a	-130.2
IIL-2 % locations	n/a	0	n/a	0
IIL-2 % time	n/a	50	n/a	50
IIL -2 Interference (dBW/RX BW)	n/a	-149.0	n/a	-149.0

Table C.2.1: FS Link A – Link Parameters

Locations	Latitude (deg)	Longitude (deg)
FS-A-1	51.56976	-0.52394
FS-A-2	51.44599	-0.28601

Table C.2.2: FS Link A – Locations

F.2.2 FS Network B

The table below defines the parameters of FS Network B (which remains unchanged and must be protected against interference greater than its IIL). The principle source of information was the Ofcom TFAC OFW 46 version 1.1. The parameters of this link were checked to ensure that the performance objectives of an unavailability due to propagation of no more than 0.01% would be met.

Licence	**FS-B**	**FS-B**	**FS-B**	**FS-B**
Direction	**Forward**	**Forward**	**Return**	**Return**
Type	**TX**	**RX**	**TX**	**RX**
Location type	Point	Point	Point	Point
Antenna height (m)	20	20	20	20
Antenna pointing	at target	at target	at target	at target
Antenna pointing at	FS-B1 RX	FS-B1 TX	FS-B2 RX	FS-B2 TX
Antenna gain pattern	Rec.F.699-6	Rec.F.699-6	Rec.F.699-6	Rec.F.699-6
Peak gain (dBi)	30	30	30	30
Beamwidth (deg)	5	5	5	5
Transmit power (dBW)	-36.1	n/a	-34.4	n/a
Centre Frequency (GHz)	1.5	1.5	1.35	1.35
Occupied Bandwidth (MHz)	1	1	1	1
Allocated Bandwidth (MHz)	1	1	1	1
Polarisation	LinHor	LinHor	LinHor	LinHor
IIL-1 % locations	n/a	0	n/a	0
IIL-1 % time	n/a	0.01	n/a	0.01
IIL-1 Interference (dBW/RX BW)	n/a	-127.6	n/a	-125.0
IIL -2 % locations	n/a	0	n/a	0
IIL -2 % time	n/a	50	n/a	50
IIL-2 Interference (dBW/RX BW)	n/a	-149.0	n/a	-149.0

Table C.2.3: FS Link B – Link Parameters

Locations	**Latitude (deg)**	**Longitude (deg)**
FS-A-1	51.5931	-0.79964
FS-A-2	51.38159	-0.74623

Table C.2.4: FS Link B – Locations

F.2.3 Mobile Network

The table below defines the parameters of the mobile network created by change of use of FS network A. The principle source of parameters was the ECC Report 45 “Sharing and adjacent band compatibility between UMTS/IMT-2000 in the band 2500-2690 MHz and other services”.

The parameters given define a standard power network i.e. EIRP of 30 dBW.

Licence	**3G**	**3G**	**3G**	**3G**
Direction	**UL**	**UL**	**DL**	**DL**
Type	**TX**	**RX**	**TX**	**RX**
Location type	Area	Area	Point	Point
Fixed or mobile	Mobile	Mobile	n/a	n/a

Number of stations	7	n/a	n/a	n/a
Antenna height (m)	1.5	1.5	30	30
Antenna pointing	fixed	fixed	fixed	fixed
Antenna pointing at	n/a	n/a	n/a	n/a
Antenna Azimuth (degrees)	0	0	0,120,-120	0,120,-120
Antenna Elevation (degrees)	0	0	0	0
Antenna gain pattern	Isotropic	Isotropic	Rec.1336 k=0,2	Rec.1336 k=0,2
Peak gain (dBi)	0	0	17	17
Beamwidth (deg)	n/a	n/a	120	120
Transmit power (dBW)	-6	n/a	13	n/a
Centre Frequency (GHz)	1.5	1.35	1.35	1.5
Occupied Bandwidth (MHz)	3.84	3.84	3.84	3.84
Allocated Bandwidth (MHz)	5	5	5	5
Polarisation	LinHor	LinHor	LinHor	LinHor
IIL-1 % locations	n/a	1	n/a	0
IIL-1 % time	n/a	1	n/a	1
IIL 1 Interference (dBW/RX BW)	n/a	-139.2	n/a	-143.2

Table C.2.5: Mobile Network – Link Parameters

Locations	Count	Latitude (deg)	Longitude (deg)
3G-Point	1	51.48142	-0.24748
3G-Area	1	51.52642	-0.31748
3G-Area	2	51.52642	-0.17748
3G-Area	3	51.43642	-0.17748
3G-Area	4	51.43642	-0.31748

Table C.2.6: Mobile Network – Locations

Note that the four points of the 3G-Area define the rectangle within which the service is to be provided.

F.3 Sharing Analysis

The CoU resulted in four interference paths, two into the FS network and two into the mobile network as follows:

Into the FS network:

1) From the mobile network uplink (mobile transmit) into the FS forward direction;
2) From the mobile network downlink (base station transmit) into the FS return direction.

Into the mobile network:

3) From the FS forward direction into the mobile uplink (base station receive);
4) From the FS return direction into the mobile downlink (mobile receive).

These are described further in the sections below. Note that all paths are in-band and no OOB analysis was undertaken.

F.3.1 From Mobile TX into FS

The interference scenario is shown in the figure below, which also shows the worst single entry interference path for one particular time step.

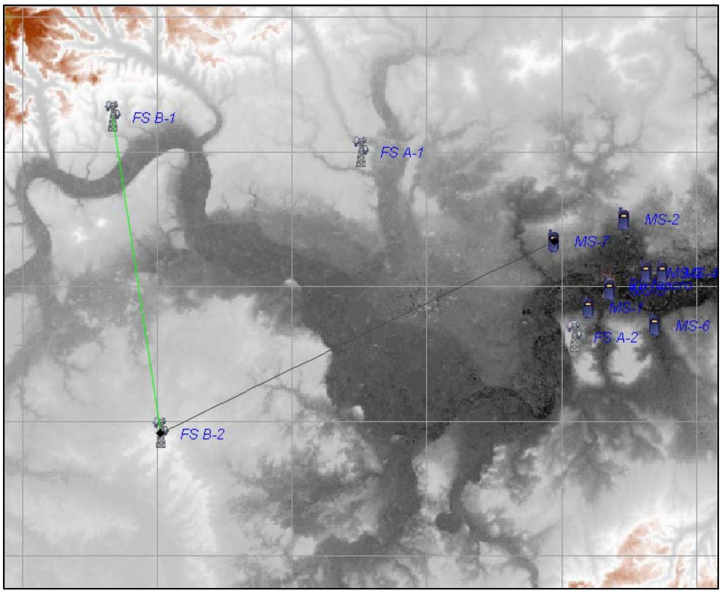


Figure 22: Mobile to FS Interference Scenario

When analysed using the GRMT the interference predicted was as shown in the figure below.

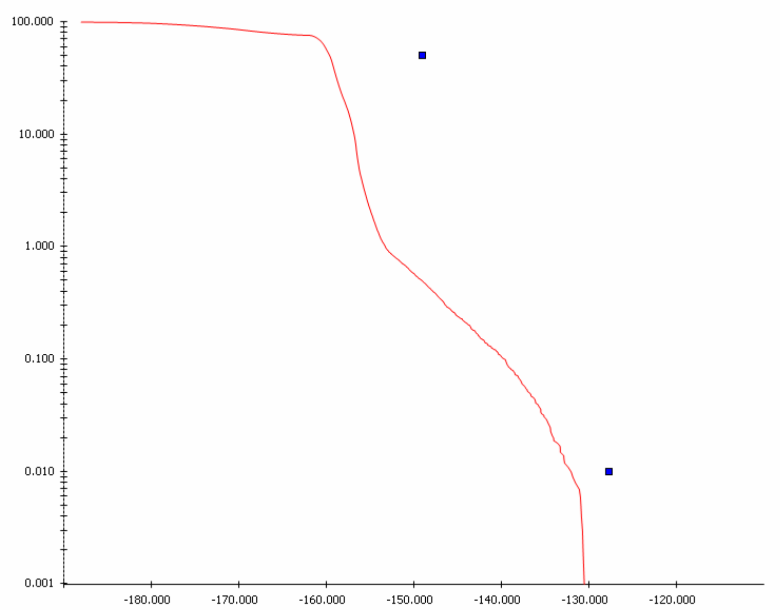


Figure 23: Probability of interference into the FS from the mobile transmitting

In the graph above and throughout this section the X axis represents interference power at the receiver (in dBW) and the Y axis the probability that that interference level is exceeded.

The two points are markers represent the indicative interference levels, in this case calculated based upon TFAC parameters. As the curve is to the left of the IIL markers, this represents interference below the threshold, and therefore for this particular interference path that the CoU would be acceptable.

The two IIL markers represent the two interference thresholds – short term and long term. Note as there is a single receiver the IIL is defined for 100% of locations i.e. not exceeded for more than 0% of locations.

Note that the interference level is dependent upon the number of mobiles simultaneously active which is defined in the database as being 7, and also their distribution, which is assumed to be uniform across the service area. It could be argued that the operator would be in breach of their licence if 8 mobiles were simultaneously active. However it is not clear how the assumption of uniform distribution of users could be enforced or monitored.

F.3.2 From Base Station TX into FS

The interference scenario is shown in the figure below, which also shows the worst single entry interference path for one particular time step.

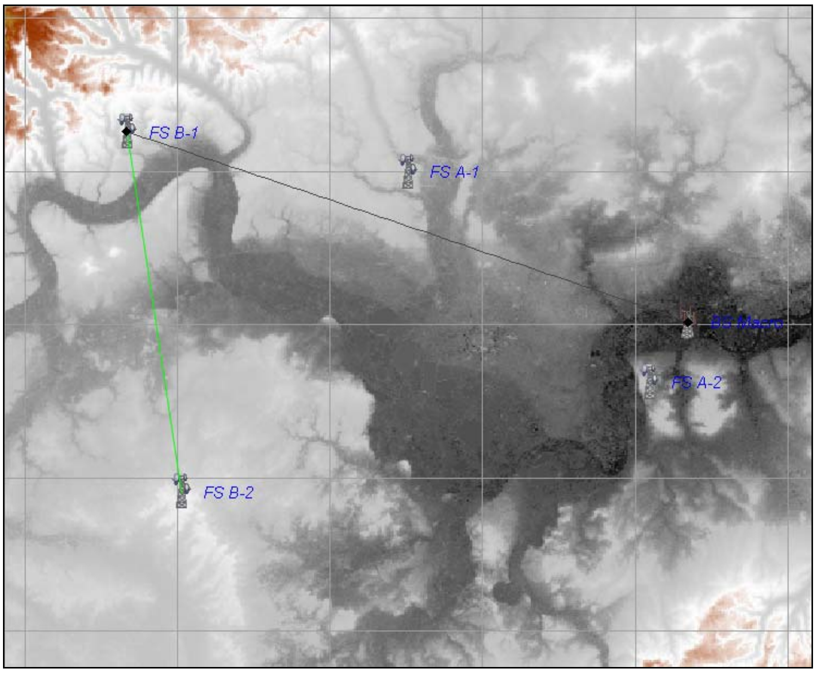


Figure 24: Base Station to FS Interference Scenario

When analysed using the GRMT the interference predicted was as shown in the figure below.

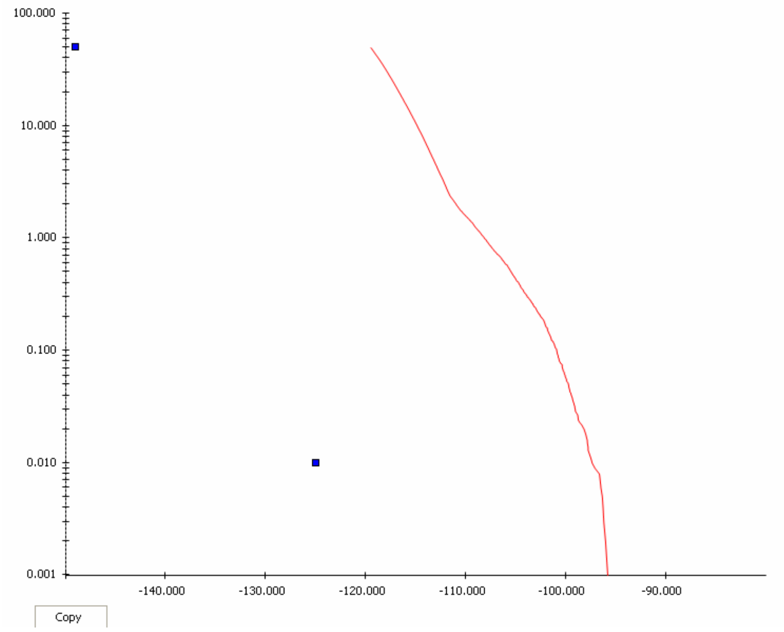


Figure 25: Probability of interference into the FS from the base station transmitting

The two markers on this graph represent the two interference thresholds – short term and long term. As the curve is to the right of the two thresholds this implies that interference would be above the required indicative interference levels.

This suggests that the CoU would be not acceptable for this interference path by a considerable margin (about 30 dB).

The mobile operator would have available a number of options, including:

- Introduce measures to reduce interference (such as only use base station antennas that point away from the FS network);
- Locate Base Stations were there is additional protection (e.g. shielding) and gain agreement from the FS operator;
- Operate only low power base stations (e.g. around 0 dBW or 30 dBm);
- Purchase FS networks over a larger area;
- Seek agreement with the FS operators to compensate them for the increased interference.

F.3.3 From FS into Base Station RX

The interference scenario is shown in the figure below, which also shows the worst single entry interference path for one particular time step.

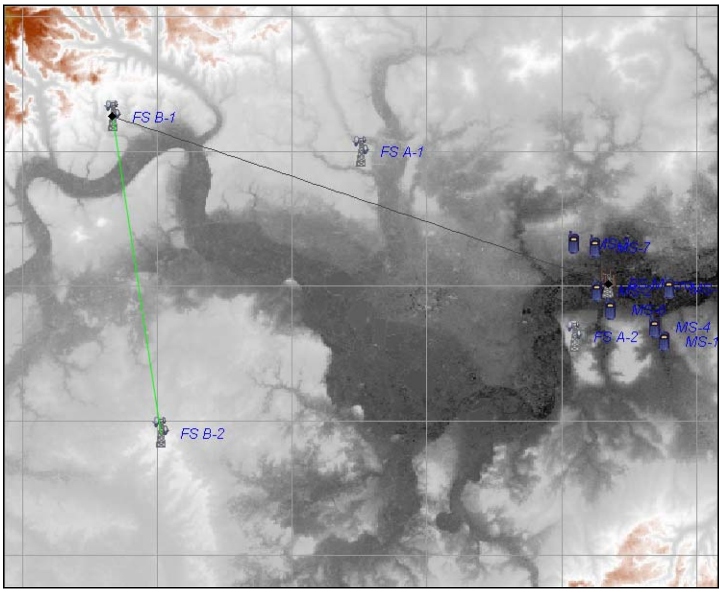


Figure 26: FS to Base Station Interference Scenario

When analysed using the GRMT the interference predicted was as shown in the figure below.

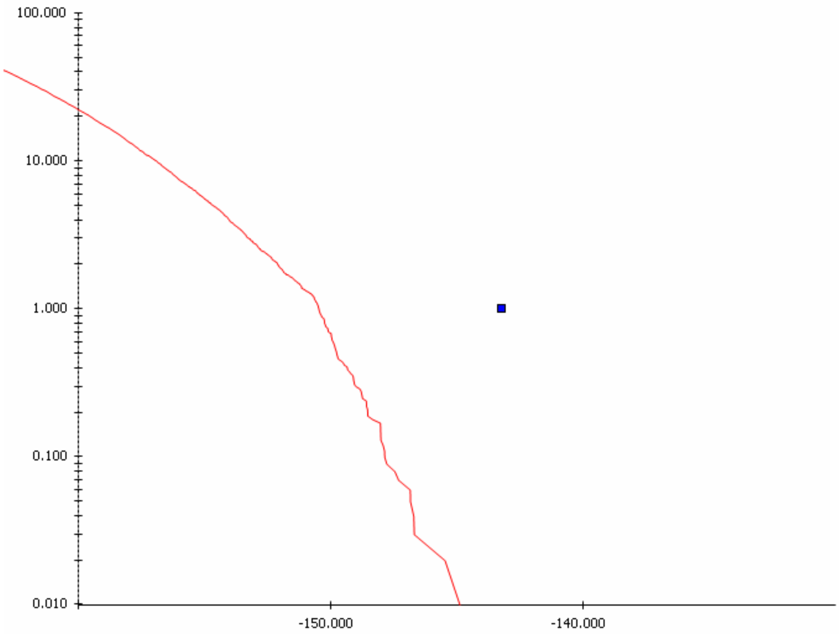


Figure 27: Probability of interference into the Base Station from the FS

Note that this licence was defined with 3 receive systems – one for each of the Base station antennas. Each had its own IIL and interference calculation. The plot shown is for the worst one – i.e. that one pointing towards the FS transmitter. The other two suffered significantly lower levels of interference.

The single marker on this graph represents the single interference threshold. However this marker represents the IIL assuming the interferer's bandwidth is the same as the victims. As noted above in the previous case study it could be the case that this requires adjustment as part of an apportionment process. However even taking this into account, the results suggest that the CoU would be acceptable for this interference path.

F.3.4 From FS into Mobile RX

The interference scenario is shown in the figure below, which also shows the worst single entry interference path for one particular time step. A grid of test points has been created over the mobile network's service area: that can also be used to contour signal strength as in the inset picture.

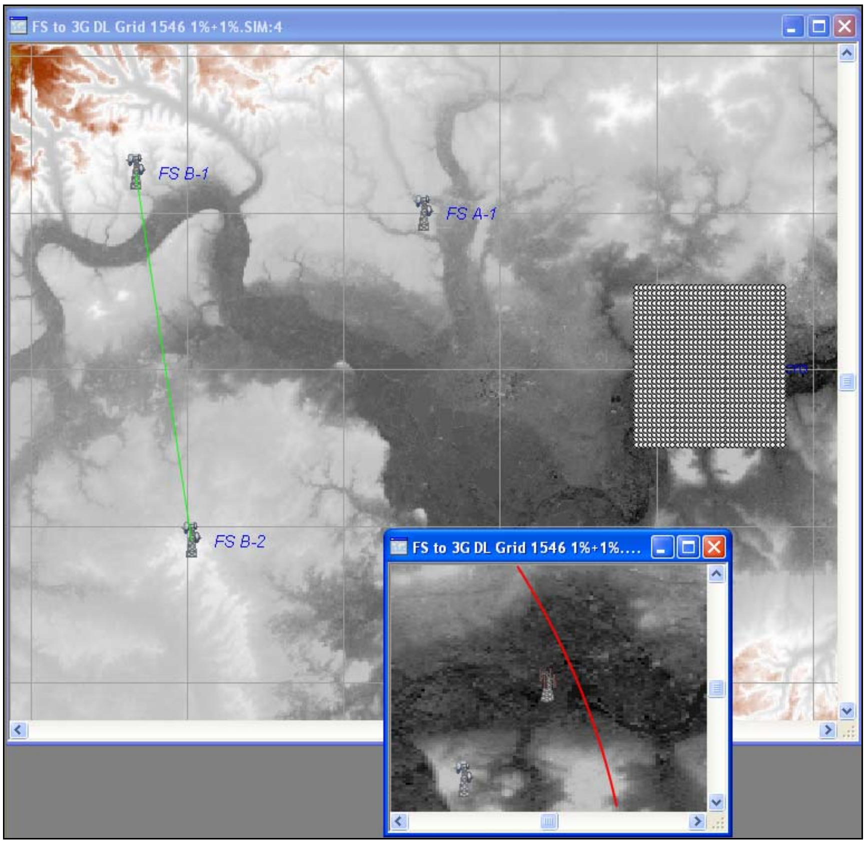


Figure 28: FS to Mobile Interference Scenario

When analysed using the GRMT the interference predicted was as shown in the figure below.

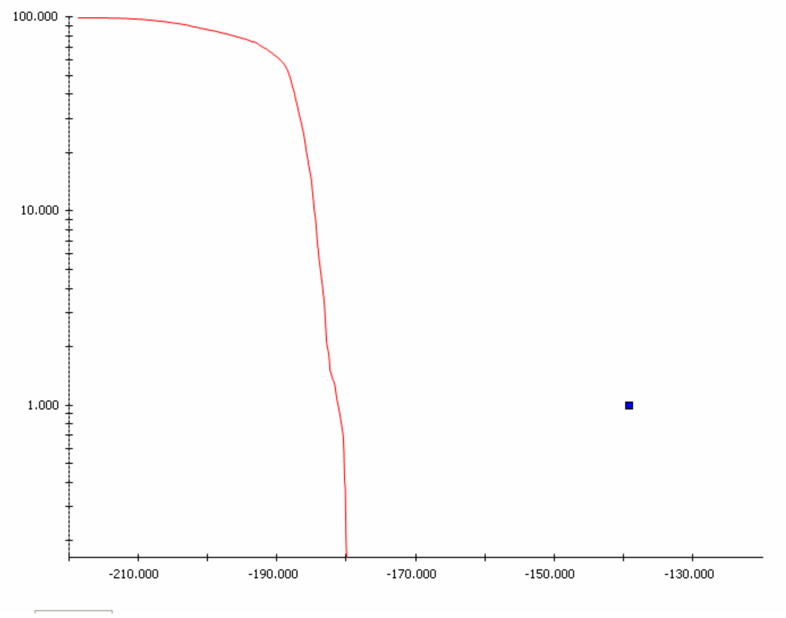


Figure 29: Probability of interference into the Mobile from the FS

Note that this licence was defined with IIL over the receive area using format:

> *Interference at the receiver should not exceed -139.2 dBW for more than 1% of the time at more than 1% of locations.*

This was examined by defining a grid of 2,424 test points (or cells) across the mobile network's service area. At each one a full Monte Carlo simulation was undertaken using the propagation model in ITU-R Rec. 1546 to generate a CDF of interference at that point. The graph above shows the CDF of interference over all test points.

Similar adjustments to apportion the IIL to take account of the relative bandwidths might also be required for this path. However even taking this into account, the results suggest that the CoU would be acceptable for this interference path.

F.4 Conclusions

In order for this change to be allowed under a SUR regime, the 3G network licence holder would need to undertake at least one of the following steps:

- Introduce measures to reduce interference (such as only use base station antennas that point away from the FS network);
- Locate Base Stations were there is additional protection (e.g. shielding) and gain agreement from the FS operator;
- Operate only low power base stations (e.g. around 0 dBW or 30 dBm);
- Purchase FS networks over a larger area;
- Seek agreement with the FS operators to compensate them for the increased interference.

G ACRONYMS AND ABBREVIATIONS

ACLR	Adjacent Channel Leakage Ratio
ACS	Adjacent Channel Selectivity
ARIR	Adjacent Channel Interference Ratio
BR	Business Radio
BS	Base Station
DAB	Digital Audio Broadcasting
CAA	Civil Aviation Authority
CDF	Cumulative Distribution Function
CDMA	Code Division Multiple Access
CoU	Change of Use
ECC	Electronic Communications Committee
EIRP	Equivalent Isotropic Radiated Power
ETSI	European Telecommunications Standards Institute
FDD	Frequency Division Duplex
FS	Fixed Service
GRMT	Generic Radio Modelling Tool
IB	In-band
IIL	Indicative Interference Level
IR	Interface Requirements
ITU	International Telecommunications Union
MoD	Ministry of Defence
MS	Mobile Service
OOB	Out-of-band
PFD	Power Flux Density
QoS	Quality of Service
RX	Receive
SFR	Spectrum Framework Review
SMG	Spectrum Management Right
SQB	Spectrum Quality Benchmark
SUR	Spectrum Usage Right
TDD	Time Division Duplex
TFAC	Technical Frequency Assignment Criteria
TX	Transmit