

# *Market Mechanisms for Spectrum Management*

## **Spectrum Liberalisation and Interference Management**

A personal view by John Pahl, Transfinite Systems Ltd, © September 2006

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### **1. Summary**

This paper analyses interference issues relating to the introduction of market mechanisms into spectrum management. It describes the current framework and identifies some of the questions that spectrum managers must be able to answer, and how competition arising from an excess of demand for spectrum over supply is leading to an increased use of market mechanisms.

The key interference paths are identified, namely in-band and out-of-band, and it is described how use of the EIRP mask alone as the licence constraint can lead to a risk of interference. Other methods to define spectrum usage rights are considered, including power flux density and the use of technical coordination based upon spectrum quality benchmarks.

In a fully liberalised environment where potentially any type of system could operate in any band – and hence cause interference into any other – there is a need for a Generic Radio Modelling Tool. The paper describes such a software tool and the algorithm that it could use to predict interference between any service and licence type.

Finally the paper describes issues relating to the international dimension and how software tools can support the regulator implement a market based spectrum management regime that provides flexibility while protecting stakeholders from interference.

### **2. Background**

The radio spectrum is a key resource for today's communications industries, a resource in demand by an ever increasing range of potential applications. A raft of new technologies and associated acronyms reflect the rush to exploit the radio spectrum for commercial and social benefits, with terms such as DTV, HDTV, DVB-H, GSM, WCDMA, CDMA-2000, DAB, WiMax, WiFi, FWA, and TETRA that jostle for attention as their proponents battle in the market place.

Change is therefore thrust upon those that regulate the radio spectrum – coming from new technologies and from increasing requests for access to spectrum from both existing and new players. Such change can not be allowed to proceed uncontrolled, for a fundamental characteristic of radio waves is that every transmitter has an impact on every receiver – signals can not be stopped, only attenuated – for example by separation in frequency and/or distance. Hence the operation of any radio system must take account of the level of the unwanted or interfering signals it would generate and/or receive and determine if it would be at a level that could be considered harmful.

In a traditional framework call “Command and Control” the national regulator of the radio spectrum tries to avoid harmful interference by controls on access to the radio spectrum such as:

1. Dividing the radio spectrum into bands, taking into account constraints such as the Table of Allocations in the ITU-R Radio Regulations;

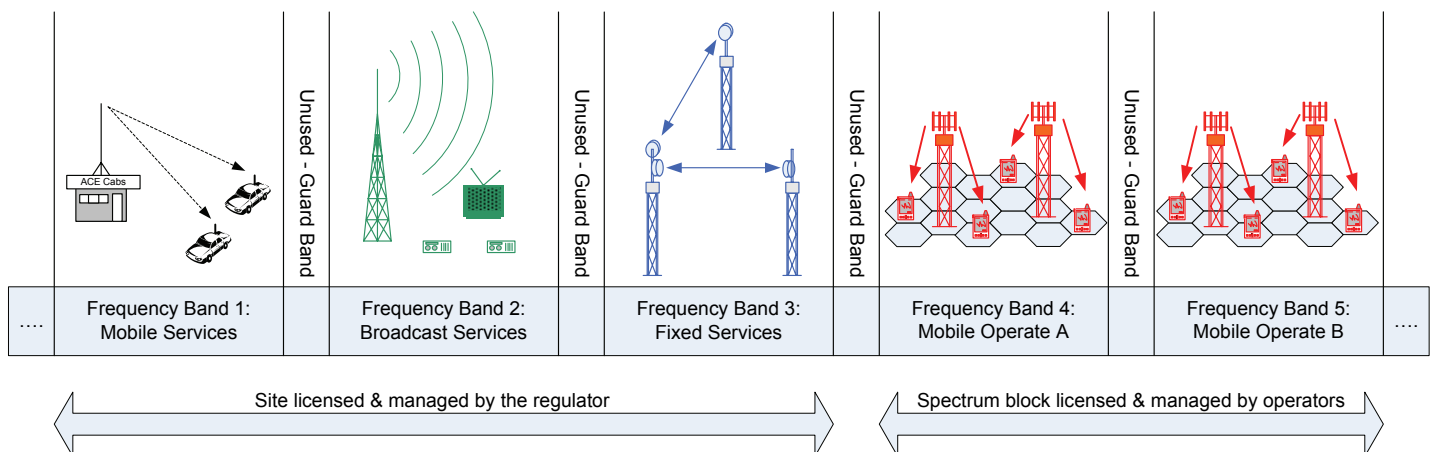
2. Allocating bands to services such as Mobile, Broadcasting, Fixed, etc (again taking into account international constraints);
3. Determining if there should be guard bands to avoid interference and if so how wide;
4. Deciding the approach to use for licensing each band (as described below);
5. Issuing licenses to spectrum users to meet their demand for the radio spectrum.

A number of approaches to licensing can be considered:

- **Site licensing**, whereby a band is used by many different operators who are constrained geographically so that the same frequency can be re-used many times. Examples of this would be business radio services or point-point fixed links, and under the command and control model these would be managed by the regulator itself which would plan deployments to avoid harmful levels of interference.
- **Block licensing**, whereby management of a block of spectrum with given geographic and frequency extent is delegated to an operator that can deploy at will equipment that meets the licence conditions. Examples of this include mobile operators that can deploy base stations to match user demand and would be responsible for planning to avoid harmful levels of intra-system interference.
- **License exempt**, whereby the spectrum can be used without prior approval as long as general operating rules are met such as use of low power. Examples of this include the 2.4 GHz band used by Wifi, Bluetooth etc.

License exempt operation has the advantage of low overheads in that users can simply purchase equipment and activate them without requiring regulatory approval. The disadvantage is that the lack of control on deployment means that no Quality of Service (QoS) can be guaranteed – see the discussion in [1]. The rest of this paper concentrates on licensed spectrum whether by site or block.

The Command and Control approach to site and band licensing is shown figuratively below.



**Figure 1: Allocation of bands to services and operators**

This approach raises a number of questions, including:

- How much spectrum should be allocated to each service?
- Which frequencies should be reserved for each service?
- How large should each guard band be?
- Which operators should gain a block licence?

- For each new technology, is it possible to clearly identify which service type it is?
- How can the structure accommodate new technologies?

If supply of spectrum is less than demand, then the regulator has the luxury of being able to make conservative assumptions and create bands with plenty of spare capacity. However answering these questions become more problematic as demand and the rate of technological change increases. If a new technology is developed that provides converged mobile / fixed / broadcasting services in which bands can it be deployed? If there are two spectrum block licences available and twenty potential operators, which ones are to gain the prize?

It is increasingly hard for regulators to answer these questions in a way that is timely, transparent and evidence driven and hence there has been increased focus on applying market forces to spectrum management.

### 3. Spectrum Trading and Liberalisation

Market forces can be introduced into management of the radio spectrum through a number of tools, including:

- Auctions**, whereby spectrum block licences are sold to the highest bidder;
- Pricing**, where owners of site licences are charged to use the radio spectrum;
- Trading**, whereby owners of spectrum usage rights whether block or site licence can sell or lease all or part of the rights associated with their licences;
- Liberalisation**, whereby the owners of licences can have their spectrum usage rights changed if they meet conditions defined by the regulator.

Of the various methods to introduce market forces into management of the radio spectrum, a recent report [2] has suggested the greatest additional economic benefits come from liberalisation.

A key concept behind spectrum trading and liberalisation is the definition of spectrum usage rights (SURs), which should identify clearly the characteristics of the “property” that is owned. A number of different methods could be used to define these rights as is discussed in document [3].

In general terms there are two types of SURs:

1. Site licence SURs that define in detail the parameters of the network to be deployed, including for example EIRP, antenna patterns, locations, frequencies, bandwidths, masks etc;
2. Spectrum block licence SURs that define the constraints on how the owner can deploy stations – e.g. limits on geography and frequency and maximum EIRP.

Note: site licence SURs could be issued by spectrum block licence holders if they are acting as a band manager.

In both cases liberalisation would give the licensee the option of change of use (CoU) whereby they can have these SURs altered. However this brings the potential for harmful interference and as Ofcom’s consultation document on Spectrum Usage Rights [4] comments:

*“In a liberalised regime ideally the only constraint on spectrum use should be controls necessary to avoid harmful interference”*

The description of SURs above is based upon authorisation to transmit, but such a right is of little worth without a degree of protection from interference from the transmission of others. It is therefore useful to ask whether there can be a right to receive without harmful interference (it is of course inevitable that there will always be some interference).

The difficulty with issuing both transmit and receive rights is ensuring they are consistent. Even with spectrum sharing between two site licences, where system parameters are typically well known and clearly specified, there can be uncertainty due to the way radio waves propagate through the atmosphere. If the regulator issues transmit rights to one and receive rights to another and there is a conflict, how is the problem to be resolved if each have equal status?

The approach taken by Ofcom is to make it clear which has priority, and in the Statement on Spectrum Liberalisation [5] it is noted that licences can expect to have the following defined:

- Emissions rights which specify characteristics of the signals the licence holder can transmit;
- Spectrum Quality Benchmarks, or SQBs, which gives an *indication* of the impact of other interference from users of the radio spectrum on the level of service which can be achieved at the receiver.

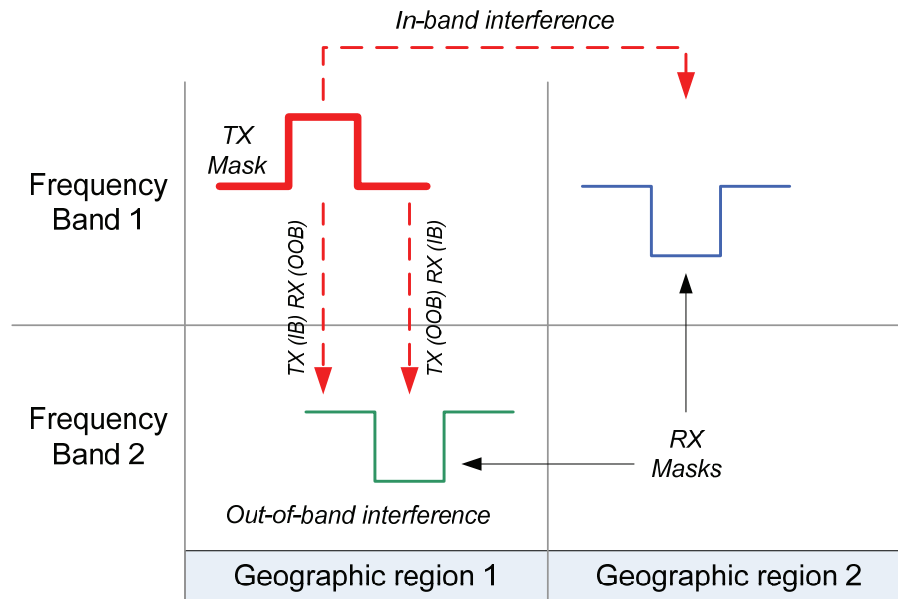
Hence the receiver is given an indication of spectrum quality but not a guarantee. There is therefore the potential for or risk of interference and it is important therefore to consider this issue further.

#### 4. Interference Problems

As noted previously, every transmitter causes a degree of interference into every receiver – the key question is how much. Interference is attenuated by the separation between the transmitter and receiver in the geographic and frequency domains. It is therefore often useful to categorise interference into two types:

- In-band interference, whereby there is frequency overlap between the transmitter and receiver operating bandwidths. Typically for both to be able to operate without excessive interference this implies a degree of geographic separation or coordinated time/code sharing.
- Out-of-band interference, whereby there is no overlap in frequency between the transmitter and receiver's bandwidth, but the geographic separation is sufficiently small that there can be appreciable interfering signal. There are two sub-types of this path:
  - In-band emissions received out-of-band (due to imperfections in the filtering of the receiver);
  - Out-of-band emissions received in-band (due to imperfections in the filtering of the transmitter);

These paths are shown in the figure below.



**Figure 2: In-band and Out-of-band Interference Paths**

The two out-of-band paths are sometimes considered separately. However in simulations it is possible to include both at once by integrating the transmit EIRP mask and the receive filter mask to calculate the net filter discrimination (NFD). Using this approach only a single out-of-band scenario needs to be considered, but the receiver characteristics must be known.

The methods to manage interference depend upon the approach taken to define SURs, and so the site licensing and spectrum block licensing cases are discussed in separate sections below.

#### 4.1 Site Licensing

To ensure holders of site licenses receive the required QoS, regulators must check that each new licence issued is consistent with all previous ones. This is done by a planning process that includes technical analysis using software tools to check for interference. The methodology used is typically optimised for each type of service, for example:

- **Business Radio:** in the UK the planning approach is described in the relevant Technical Frequency Assignment Criteria (TFAC), namely document OFW 164, which also references CEPT T/R 25-08 and the Berlin Agreement.
- **Fixed Service and Earth Stations:** in the UK the planning approach for fixed links are described in a series of TFACs and coordination with satellite earth stations is based upon the process in ITU-R RR Appendix 7.

The methods used for these two services are very different – for example different protection requirements, system parameters, and propagation models.

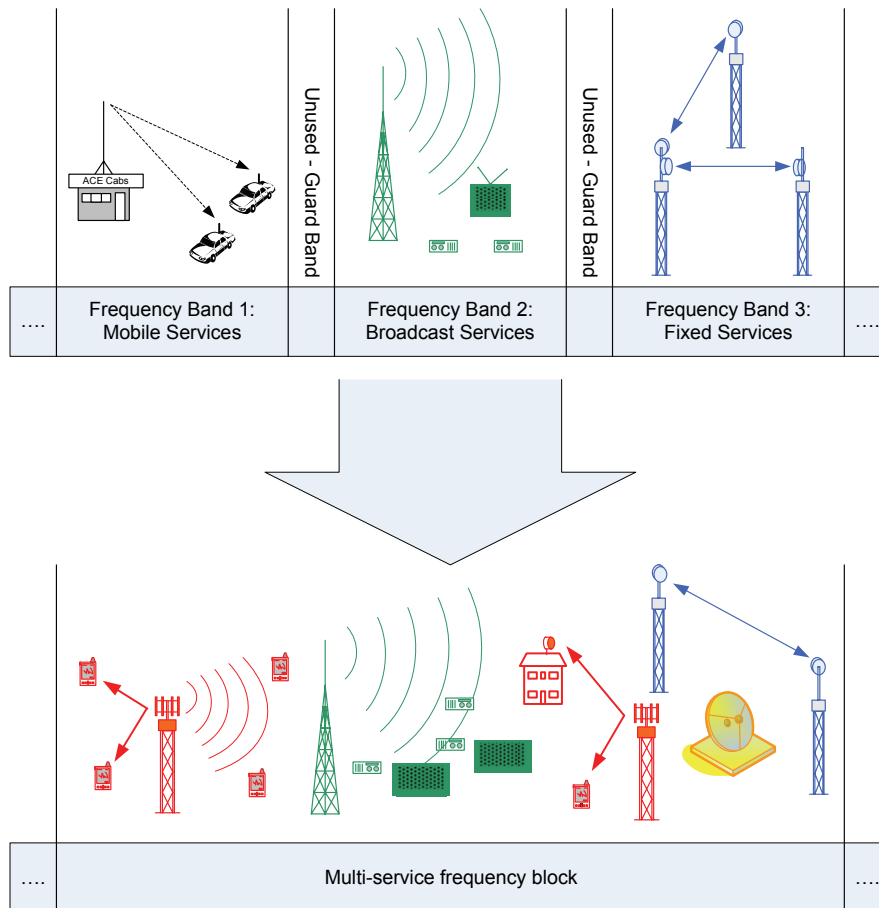
Site license holders are then required to pay administrative incentive pricing (AIP) using an algorithm that should in principle charge according to amount of radio spectrum used. This pricing formula again varies by service and frequency band.

However in a liberalised regime there could in theory be any service operating in any band – including new services not yet defined. Existing planning tools optimised for one or at most two specific services would be unable to analyse the potential for interference between them. This could lead to either changes that should be approved being rejected (as the tools are not available) or licensed radio users experiencing harmful interference.

Another implication of market forces is the potential for gradual transition of services from one band to another – such as fixed links moving to less congested (and hence cheaper) higher frequencies while the lower bands then become available for mobile and broadcasting services. This transition could be lengthy and if planning tools can only model one or at most two services at a time there could be long periods where significant spectrum is unused.

Similarly the guard bands are currently unused and could be made available if it could be ensured that the deployments within them would not cause unacceptable levels of interference.

The objective should be a liberalised regime which allows any service to share with any other service as in the figure below.



**Figure 3: Liberalised Vision for Site Licenses**

In this example the three single-service frequency bands have been amalgamated into a single multi-service block, removing the guard bands. The existing assignments have been transferred into this new regime and then two forms of changes have been permitted:

1. Change of use: existing licences can request that they be permitted to change their licence from one form to another. So in this example the taxi company has changed into a mobile / broadcasting application and the broadcasting service is now transmitting HD-TV;
2. New generic assignments: entrants can be permitted to access to the band providing a range of innovative new services not limited by existing categorisation. So in this example a company is now providing fixed and mobile services using a WiMax like technology.

What is required to enable this vision is a methodology that can predict the interference that would be caused by any service into any other service and software that could implement this methodology. Such a Generic Radio Modelling Tool is described further in section 5.

## 4.2 Spectrum Block Licensing

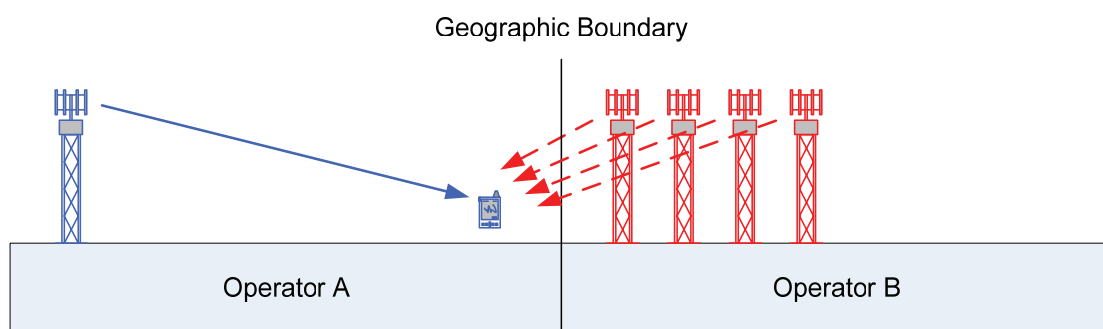
Spectrum Block Licenses are typically issued through the auction process. The owner therefore pays a fixed amount upfront and then is free to deploy transmitters without further payment for a fixed period subject to the conditions of the licence.

Traditionally the conditions associated with each licence have restricted their use to a particular technology – for example use of GSM or WCDMA standards. However in a liberalised regime licence owners might want to change from one technology to another or be free to use a new licence for whatever purpose they feel is most appropriate. In such a regime there is considerable flexibility, but that can bring the potential for interference.

It is sometimes suggested that the interference issue can be resolved by controlling the maximum EIRP mask that can be deployed. However as will be seen in the discussion below this can still result in significant levels of interference.

With spectrum blocks the greatest potential for interference is at the boundaries whether in the frequency or geographic domains.

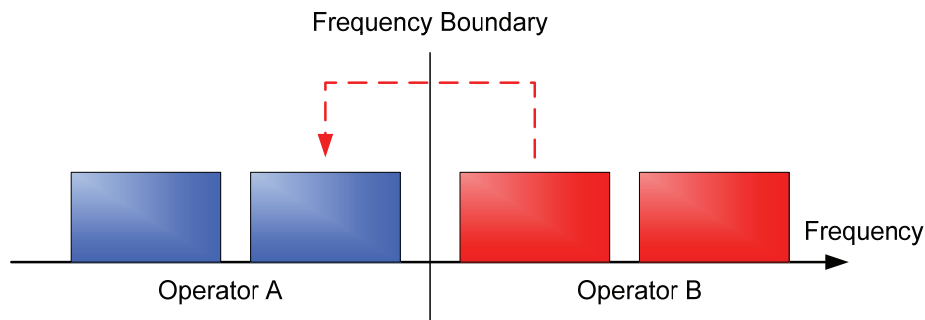
For example the figure below shows the geographic boundary where there can be in-band interference between Operator A and Operator B.



**Figure 4: Interference across geographic boundary**

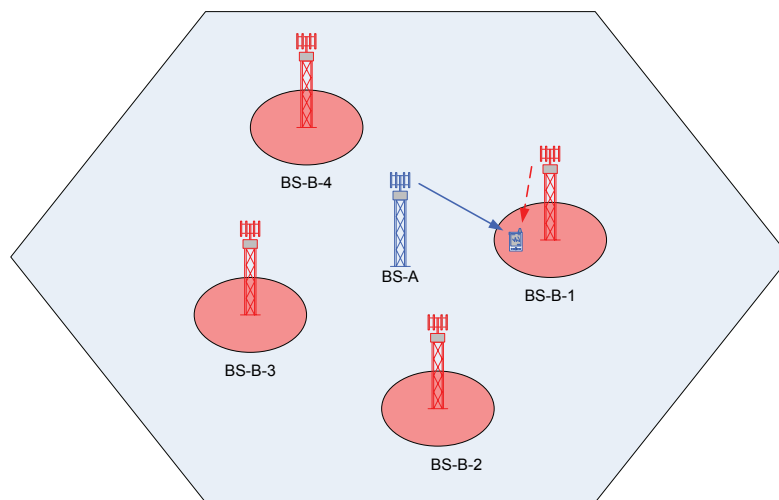
Here Operator B has deployed base stations directly next to the boundary and so is causing high levels of interference into the licensed area of adjacent Operator A. Not only is this caused by minimal separation between interfering transmitter and victim receiver, but also due to the aggregation from multiple transmitters. Each one is transmitting with an EIRP constraint but there is no control on the aggregation.

Similar problems can be caused by out of band scenarios.



**Figure 5: Interference across frequency boundary**

As noted above contributions to the out-of-band interference could come from either the transmitter's in-band emissions being received out-of-band or the transmitter's out-of-band emissions being received in-band. There is then the potential for interference as in figure below.



**Figure 6: "Punched holes" due to Adjacent Band Interference**

Near the location of transmitters in the adjacent band, interference can be expected to rise to a harmful level. If the only control is the EIRP mask each operator would have no control on the location and number of transmitters deployed by other operators in adjacent bands, and hence risk degraded QoS.

In a traditional command and control regime interference from adjacent bands is controlled either via guard bands or by rigid determination of the technology that can be deployed to a single well defined standard.

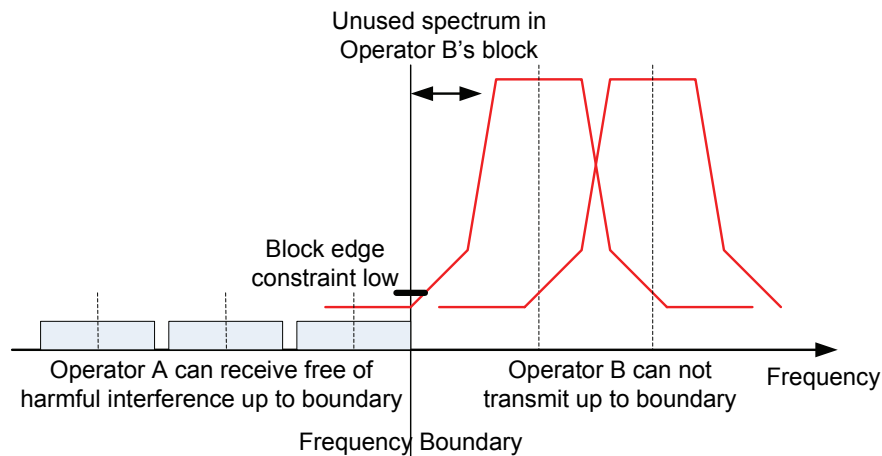
Hence it is feasible for two 3G / WCDMA operators to be issued with licences as the standard includes mechanisms that will ensure that operation will in practice be feasible in adjacent bands. However if the licence conditions are relaxed from specification of a single standard to a technological neutral approach simply based upon EIRP then this would introduce a risk of interference.

This was discussed in document [3] which described a number of Case Studies relating to Technological Neutral Spectrum Usage Rights. It notes that for the case of two 3G networks in adjacent bands, simply removing one of the components of the WCDMA standard, namely power control, can result in unacceptable interference for up to 30% of the time.

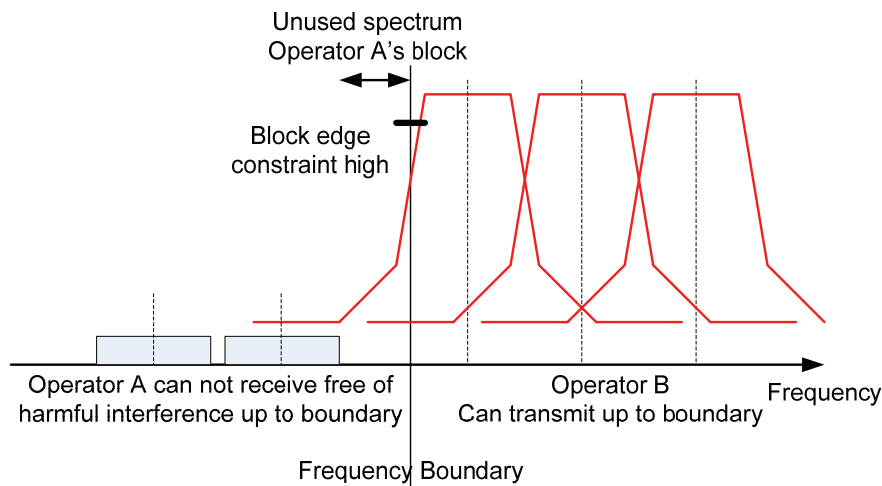
One solution to avoid this interference is to increase frequency separation – effectively introduce guard bands. These can be either side of the edge of frequency block depending upon whether the



EIRP is permitted to be a high or low value at the block edge as in the figures below. In either case spectrum becomes potentially unavailable.



**Figure 7: Tight EIRP Mask constraining transmitters**



**Figure 8: Relaxed EIRP Mask constraining receivers**

A standard represents a simple but effective method to manage interference as it defines many of the parameters of the network. In the case of two WCDMA networks the key attributes that allow operators to make use of adjacent bands are:

1. Both wanted and victim use power control to limit emissions to the minimum necessary;
2. Both wanted and victim networks have similar mixes of traffic types, user densities, and time of day variations;
3. Both wanted and victim networks typically use similar size cells – i.e. both tend to use small cells in urban areas and larger cells in rural area;
4. Both wanted and victim use similar carriers with NFD between adjacent bands of around 40 dB.

If any of these attributes change – for example due to liberalisation of existing bands or different choices made by operators purchasing new spectrum – then there is the potential for interference.

Hence there could be problems if:

1. One operator switched off power control (for example using adaptive modulation to maximise data through-put);
2. One operator provides a voice service while the other a data service;
3. One operator deploys a high density network in a rural area where the other has low density of stations;
4. One operator uses narrow band GSM adjacent to wide band WCDMA.

In these cases either there would be the risk of interference or the regulatory regime would have to put in place controls on what systems could be deployed.

Document [3] described a number of methods that can be used to manage in-band and out-of-band interference, including using PFD and technical co-ordination discussed further below.

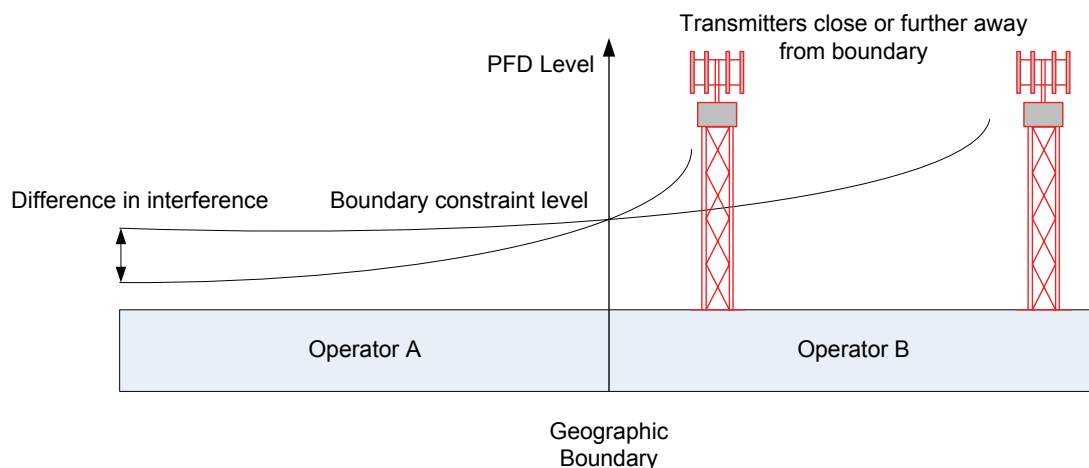
#### 4.2.1 PFD

Power Flux Density (PFD) can be used to control both in-band and out-of-band interference for spectrum block licences. For in-band scenarios a PFD level (or alternatively field strength) can be defined at a boundary and deployments permitted unless they would exceed the trigger level. PFD levels can either be defined as aggregate (the total from all transmitters from a licence) or single entry (from any one transmitter). As a particular problem with uncontrolled deployment is the aggregation effect the former is usually preferred.

The next question is usually at what level the PFD constraint should be set? As with the EIRP mask with the frequency boundary, there is a choice between:

- A high PFD level so that transmitters can operate close to the boundary but receivers suffer interference immediately beyond it;
- A low PFD level so that receivers can operate close to the boundary but transmitters must be located further away.

One problem with PFD masks is it not possible to determine from a constraint on a boundary how the interfering signal decays beyond it. As can be seen in the figure below, in both cases the PFD constraint is just met but there is a large difference in interference beyond the boundary.



**Figure 9: PFD beyond boundary**

Not only is the slope of the decay in interference not known, but it could be positive – i.e. interference could increase as separation distances increase if the victim is for example at the top of the hill with line of sight of the transmitters.

A solution to the above problems is to define the PFD level low and assume it is constant beyond the boundary. However that brings a further problem – the variation in signal due to propagation effects. If the boundary is set low then transmitters must operate further away from the boundary in order that interfering signals have decayed sufficiently to meet the limits. However the further you are away from a transmitter the more the variation due to propagation and hence it is also necessary to set an associated percentage of time.

The result is a definition such as:

*The aggregate transmitted PFD at or beyond [definition of boundary] should not exceed [X] dBW/m<sup>2</sup>/Ref.BW at any height up to [Y] m for more than [Z] % of the time*

A similar approach can be used to define the out-of-band PFD mask. As noted above, close to transmitters there will be a zone of interference, and hence it is not possible to define a PFD level that is met for all locations. Hence the out-of-band PFD mask is of the form:

*The out-of-band PFD at any point up to [X] m above ground level should not exceed [Y] dBW/m<sup>2</sup>/Ref.BW for more than [Z]% of the time at more than [W] % of locations in any [reference area]*

The values of X, Y, Z, W are likely to vary depending upon location. For example urban areas could experience high levels of interference at many locations while a rural area could experience lower levels of interference and at only a few locations. In addition, rather than using a reference bandwidth, a reference receiver could be used to ensure control on both the out-of-band paths.

The two PFD masks can be used to manage spectrum blocks for both the in-band and out-of-band paths. There would be the choice of:

- Self-certification, whereby the operator undertakes their own checks that the PFD levels are within the limits proscribed;
- Regulator validation, whereby the operator informs the regulator where they intend to deploy their stations, which are then checked against the limits in their licence.

In either case tools would be required for use either by the operator or the regulator that could model the wide variety of systems and services that an operator could deploy in their block of spectrum.

#### 4.2.2 Technical Coordination

One issue that was raised in the consultation exercise about the use of out-of-band PFD masks was that the location of interference would not be known – it would just be a probabilistic approach to interference. This could be resolved by the use of registrations and/or technical coordination.

In the case of technical coordination, each station that is deployed is checked for compatibility with existing deployments of other networks. Each transmitter would be registered in a database – typically managed by the regulator. In addition the database would store regions to be protected from interference including definition of the threshold of harmful interference. This would represent the spectrum quality benchmark (SQB) that the regulator would be prepared to offer the licensee.

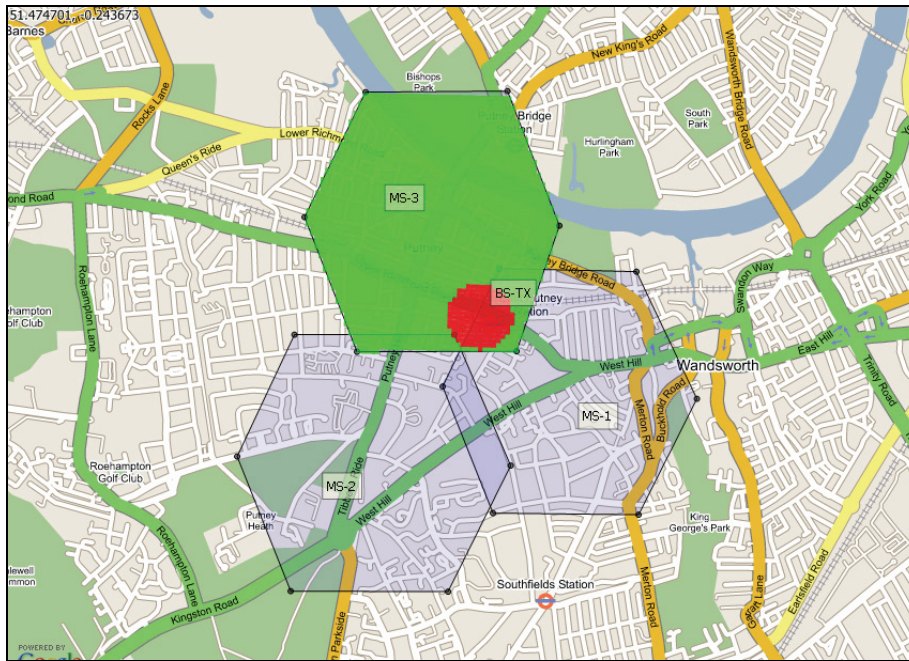
Software following a defined methodology is then used to predict whether the interference generated by transmitters would exceed the SQBs of previously registered receivers. This would be done in two directions:

1. Calculating interference from newly registered transmit systems into previously registered receive systems;

2. Calculating interference from previously registered transmitters into newly registered receive systems

Both checks would have to pass for the newly registered system, comprising transmit and receive systems, to be authorised. This approach typically introduces the principle of first-come first-served (FCFS) in which stations that are registered are protected from interference from stations which are deployed later.

This approach is often used for bands which use highly directional antennas – such as point to point fixed links and satellite earth stations – but in principle it could be applied to all other bands. For example the figure below shows an assessment of the impact of introducing a WCDMA base station on the cells of another WCDMA network operating in adjacent spectrum.



**Figure 10: Technical Coordination of Base Stations**

The result would be a scenario similar to the site licensing interference problem whereby theoretically a station of any service could have to be assessed against any others, requiring a tool such as the Generic Radio Modelling Tool discussed in the next section.

It is sometimes argued that such an approach could introduce significant administrative overhead; however such data is already available in operator's databases and often provided to regulators for other purposes (e.g. the Sitefinder web site used by Ofcom for mobile service base stations [6]). Another argument is related to security: however such information would initially be available only to the regulator and in the age of Google Earth it is likely such data will become public domain at some point.

Hence with suitable software systems a technical coordination approach could be used for any of the spectrum block bands and should result in high spectrum efficiency as the locations of all transmitters and receivers would be known and interference accurately calculated.

## 5. Generic Radio Modelling Tool

As noted above there is a need for a flexible interference analysis tool to support regulators and operators within a flexible liberalised framework of spectrum management. Such as project is the Generic Radio Modelling (GRMT) tool as described in [7].

The objective of the GRMT is to be able to analyse the potential for interference between a wide range of licences based upon their SURs in order to support the goal of spectrum liberalisation.

It should be able:

- For site licences: determine whether a new licence or CoU licence is consistent with the spectrum quality benchmark of other licences already issued;
- For band licences: determine whether a new deployment or change to existing deployment is consistent with the licensing conditions, whether IB PFD, OOB PFD, or site by site coordination using FCFS.

Note that bands licences used to provide many site licences (e.g. by a band manager) would require both forms of checks.

In order to assess whether a new licence / deployment or CoU application could be approved or rejected it is necessary to include the receiver characteristics in the definition of SURs. The most critical of these is the definition of the SQB and a suitable format is:

*Interference at the receiver should not exceed X dBW for more than Y % of the time [at more than Z % of locations]*

This format was selected as it represents a transparent, measurable, and technology neutral definition of spectrum quality. Apportionment rules are used to convert aggregate SQB thresholds to single entry ones. This measure can also be mapped onto others such as power flux density by noting that for an isotropic receiver (where  $\lambda$  is the wavelength in metres):

$$PFD = I + 10 \log_{10} \left( \frac{4\pi}{\lambda^2} \right)$$

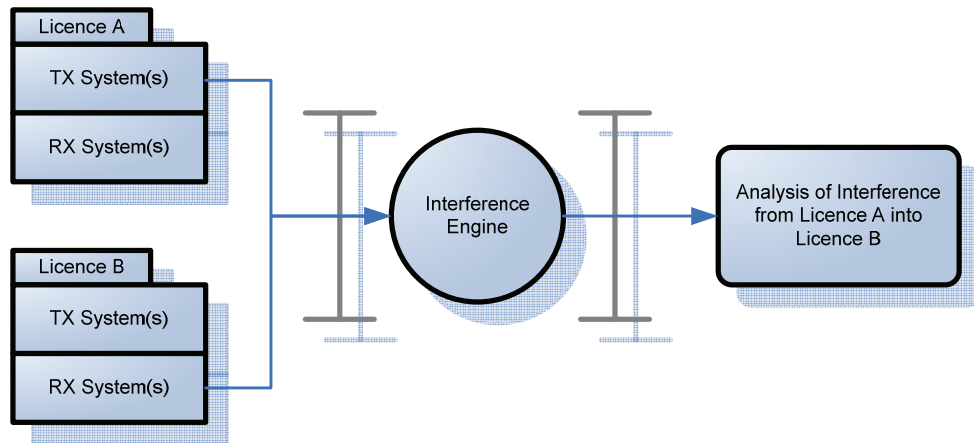
Use of this metric by the GRMT implies that the interference assessment can be undertaken independently of the planning process. This could be interpreted as an implication of permitting liberalisation, as it could be argued that a CoU request should not be rejected if the victim network is inadequately planned.

Using a defined database format for SURs and the SQB measure of interference, the GRMT Algorithm defines the methodology to undertake the following two tasks:

*Task A. Identify which Licenses should be analysed to see how they would be affected by a proposed Change of Use.*

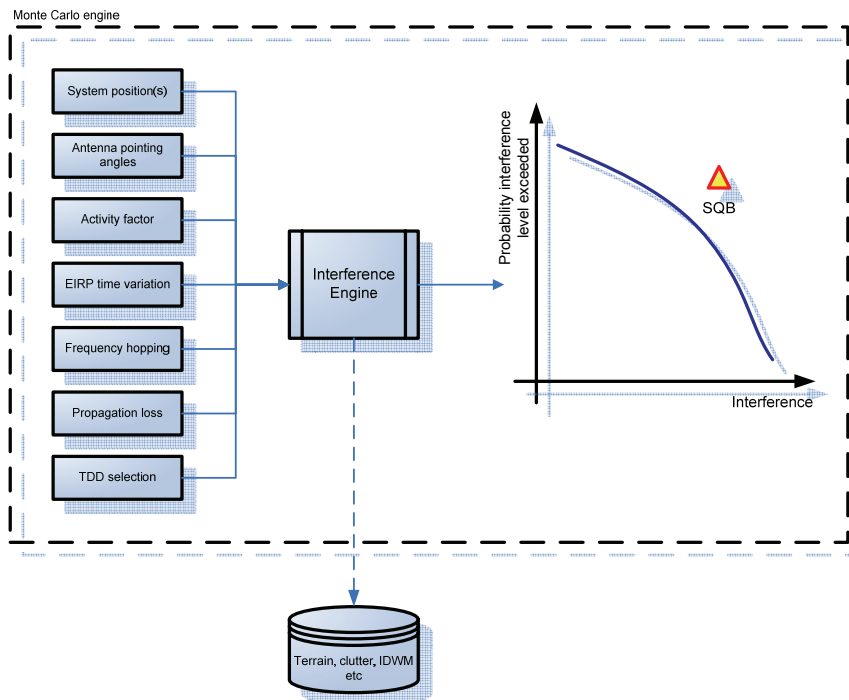
*Task B. For those Licenses that have been identified as requiring further analysis, calculate what would be the impact of such a proposed change on their Spectrum Quality Benchmark(s).*

Task B implies that the GRMT must be able to calculate interference between any two licences, as shown in the figure below.



**Figure 11: GRMT Interference Engine**

The GRMT Algorithm is defined in a specification document which gives the assumptions, calculations, steps and methodologies used to undertake these two tasks. At its core the interference engine uses Monte Carlo methods whereby the key time-varying parameters are convolved together as in the figure below.



**Figure 12: GRMT Monte Carlo Engine**

At each Monte Carlo sample GRMT undertakes a detailed interference calculation that includes:

- TX EIRP (and variations in time and frequency domains);
- TX Relative Gain (including antenna pattern and pointing angles);
- Path Loss (including the effect of terrain and clutter using suitable databases, the propagation model in ITU-R P.452, and whether the stations are in-door or out-of-door);
- RX Gain (including peak gain, antenna patterns and pointing angles);

- RX Losses (such as feeder loss);
- RX Filter Mask (to convolve with the EIRP frequency mask to calculate the net filter discrimination or NFD);
- System factors (frequency hopping, activity factors, time-division duplex, polarisation etc).

A key factor is the propagation model used to calculate the loss between the transmitter and receiver. Ideally a single model would be available that would cover the range of frequencies, antenna heights, and path types under consideration. A number of propagation models were considered including ITU-R Rec.P.452, 1546, and COST 231. The approach selected by GRMT was based upon ITU-R Rec.P.452, with extensions and adjustments to permit its use in frequencies below 700 MHz and a 50m terrain and clutter database.

By repeating the interference calculations many times, the Monte Carlo engine generates a cumulative distribution function (CDF) of interference against probability exceeded. This can then be compared against the SQB threshold to give a pass or fail decision.

The GRMT Algorithm has been implemented in software to run on a standard Windows XP PC. Version 1 of the software included an interface to a database of licences in SUR format and provided a graphical user interface as in the figure below.

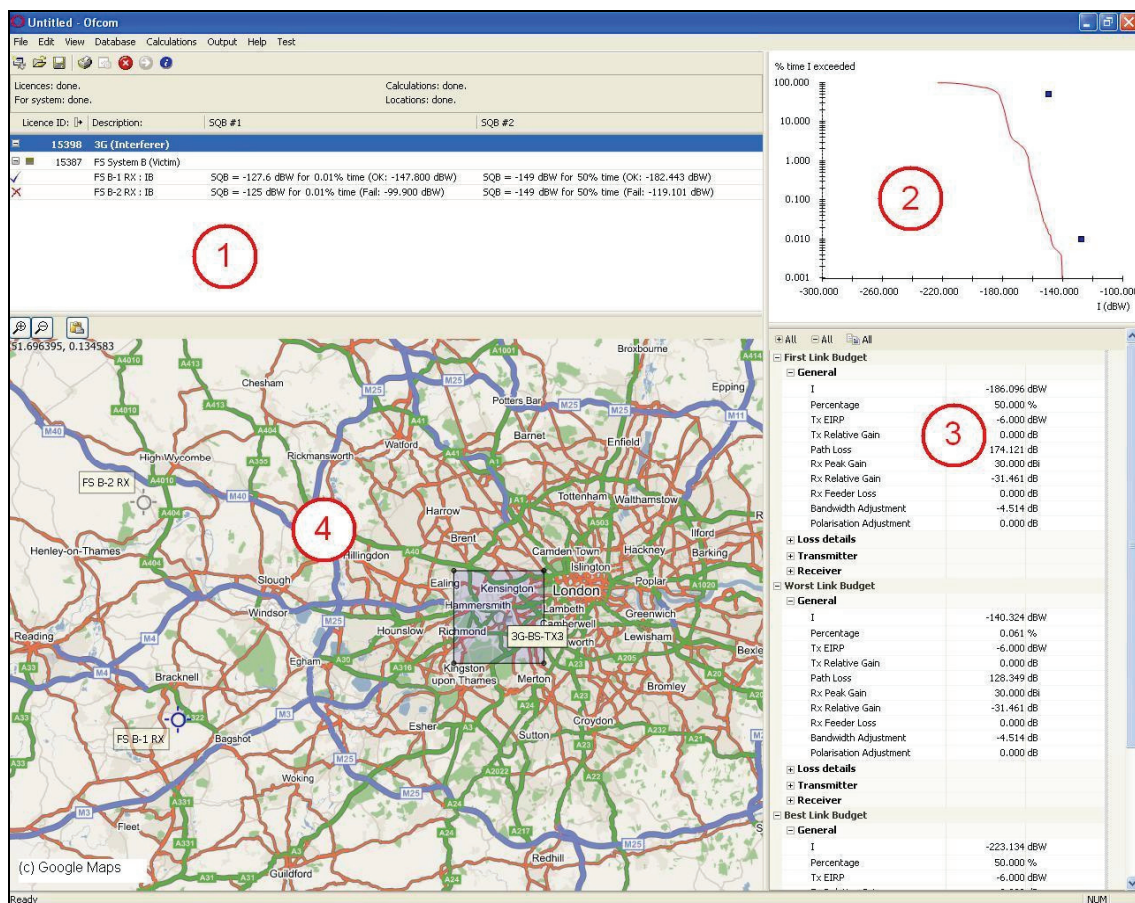


Figure 13: GRMT User Interface

The four windows give information about the CoU examination:

1. This window shows the list of potentially affected licences to be examined. It shows which systems are taken as interferers, which systems are victims, what the SQBs are, and at the end of the run whether the examination passed or failed.

2. This window shows statistics for the selected licence – in this case the cumulative distribution function (CDF) of the interference against probability of interference exceeded. The SQB thresholds are shown as markers.
3. Example link budgets for the selected licence – this can be used to sanity check the results, ensuring the positions, antennas, EIRPs etc are as expected.
4. Map showing the locations of the selected licence systems and the interferers. Single point systems are shown as markers (red = interferer, blue = victim, grey = other), while area systems are a set of boundary points with connecting line.

The user interface also included additional tools, such as to examine path profiles, and a database editor.

As described in the GRMT project's Final Report [7], a number of test cases were examined which showed that the prototype GRMT could be used to assess whether a CoU should be approved or rejected. Some test cases were found to result in interference above the victim's SQB (and hence would be rejected) while others would be below the victim's SQB (and hence would be approved).

In the case where the CoU should be rejected steps were identified that the licence owner could take prior to re-submitting the change. In either case a report could be generated by the prototype GRMT to document the regulators decision.

## 6. International Dimension

Liberalisation of radio spectrum within one country must remain consistent with its international obligations. These impose constraints defined in documents such as the ITU-R Radio Regulations and Recommendations, ECC Decisions and Recommendations, and bi-lateral agreements.

A typical format is that used in ECC Rec 01-01 "Border Coordination of UMTS/IMT-2000 Systems" [8]. This identifies field strengths (which can be converted to PFD levels) not to be exceeded on the country's border without the agreement of the other.

Different values are given for:

- Neutral vs. Neutral – i.e. each party has equal rights to use a frequency band but neither must exceed a value of 45 dB $\mu$ V/m/5MHz at a height of 3m above ground at or beyond the boundary;
- Preferential vs. non-preferential – i.e. one party has preferential access to a frequency band and can operate as long as they do not exceed the higher field strength of 65 dB $\mu$ V/m/5MHz at a height of 3m above ground at or beyond the boundary (with the other party at the lower value as for neutral vs. neutral).

Typically each country either side of a border have by default equal numbers of preferential and non-preferential channels.

These field strengths or PFD on boundary constraints can fit into a liberalised regime by being implemented as constraints on SURs for both site licences and spectrum block licences. This process is identical to that employed between co-frequency spectrum block licences within a country's spectrum liberalised regime.

More detailed spectrum coordination can also be employed – such as use of technical coordination across borders by exchanging information about the SURs of each system. This can lead to a FCFS approval process across boundaries – as is explicitly included in the ITU-R's coordination process.



This can be acceptable between countries with equal levels of industrial development but can lead to tension if the country on one side of the border is much more advanced than the other or one is newly independent. There would be the fear that the developed country would deploy a large number of sites which would then have priority over any that the other country would install in the future, restricting its ability for economic advancement.

In such circumstances the preferred / non-preferred bands can represent a method of protecting the radio spectrum resource of the developing or newly independent country until it is sufficiently advanced in its economic development. More developed countries wanting greater access to the radio spectrum at frequencies where the other country has a preferential channel could lease access closer to the boundary. Hence the market mechanism with preferential channels and boundary conditions could be used to protect a developing nation's rights while allowing controlled use of the radio spectrum.

## 7. Software Tools

As noted above software tools such as GRMT can be used to manage interference within a liberalised spectrum management regime. Tools can be used:

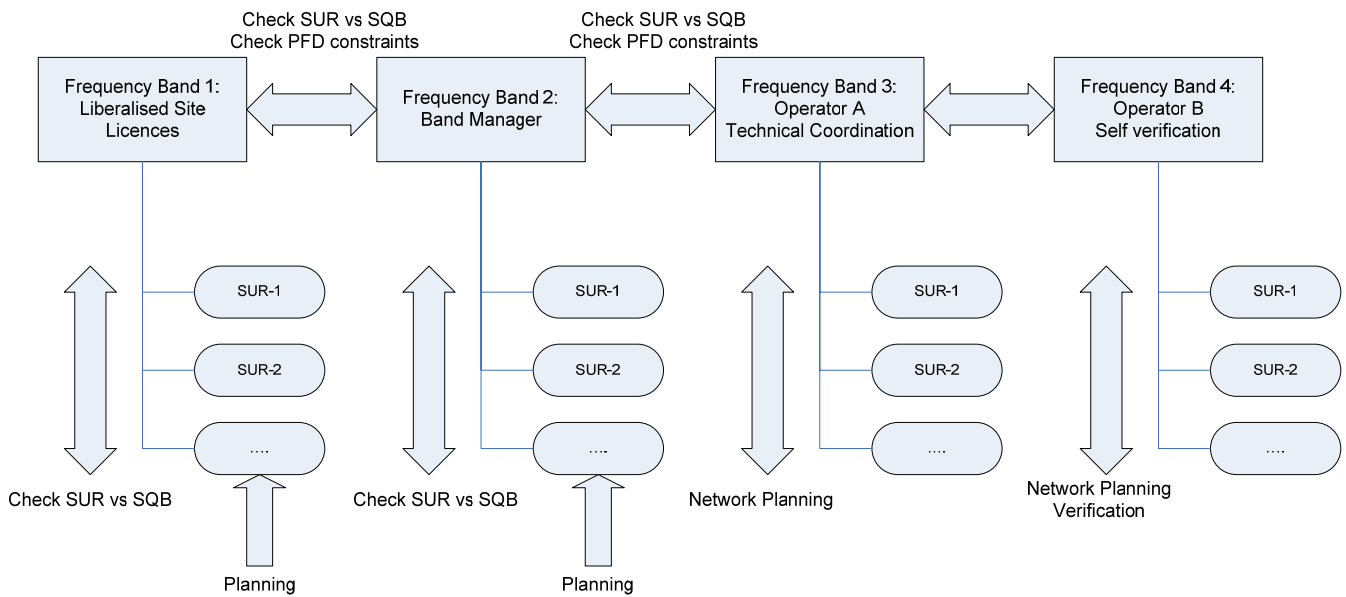
### By the regulator to:

- Check new site licences in bands managed by the regulator against other site licences either in that band or in adjacent bands (e.g. checking the emission rights are consistent with the SQBs requested);
- Check new site licences in bands managed by the regulator or by band managers are consistent with agreements with other countries (e.g. checking against PFD on country borders);
- Check changes to deployments in spectrum block licences are consistent with registered deployments in other spectrum block licences and site licences;
- Check changes to deployments in spectrum block licences are consistent with licence terms and agreements with other countries (e.g. checking against PFD on licence or country borders).

### By operators:

- To check applications for new site licences will be approved and make best use of the radio spectrum;
- To check changes to deployments in spectrum block licences will be approved when changes must be validated by the regulator (e.g. request the set of SURs that just passes and optimises revenue and/or service quality);
- To check changes to deployments in spectrum block licences are consistent with licence terms when undertaking self-verification (e.g. checking new deployments meets PFD limits);

The overall architecture is shown in the figure below.



**Figure 14: Checks on SURs, SQBs and PFDs to support Spectrum Liberalisation**

Software solutions can therefore be used by regulators to facilitate the introduction of a liberalised approach to spectrum management while remaining in control of the interference problem. An example of such a software solution is Transfinite's product currently under development, namely *Visualyse Spectrum Manager*, which is planned to include:

- Distributed client – server architecture including support for web based user interfaces;
- Database of licences in generic SUR format;
- Interference engine capable of calculating interference and comparing against SQB thresholds;
- Tools to analyse whether PFD or field strength on boundary constraints are met (whether between spectrum block licences or international coordination);
- Support for licensing approval procedures.

## 8. Conclusions

Liberalisation of spectrum management is forecast to generate significant economic benefit but must be carefully managed to avoid harmful interference. A regulatory solution must include at least the following three components:

1. A clear definition of the Spectrum Usage Rights (SURs) associated with each licence, with carefully selected SUR parameters and values;
2. A framework of procedures and rules that protects the rights of existing spectrum users while facilitating changes and introduction of new uses of the radio spectrum;
3. Availability of software tools that can support the process by undertaking interference analysis to ensure licensee's SQBs are met and also that they meet obligations such as PFD on or beyond a boundary.

## 9. References

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## 10. Biography

John Pahl is a Director of Consultancy at Transfinite Systems Ltd and was involved in the studies for Ofcom of Technology Neutral Spectrum Usage Rights and was project manager for development of the Generic Radio Modelling Tool. He has extensive experience of ITU-R activities having attended WPs in SGs 1, 3, 4, 6, 7, 8, and 9 as well as CPMs, RAs and WRCs.

Transfinite is the developer of the Visualyse range of simulation tools including:

- **Visualyse Professional:** a flexible study tool that can be used for system design and sharing studies for a very wide range of radio communication systems;
- **Visualyse Coordinate:** a tool that supports the coordination of satellite earth stations with terrestrial services such as fixed links;
- **Visualyse GSO:** a tool that supports the coordination of GSO satellite networks with other networks;
- **Visualyse EPFD:** a tool to support the verification that non-GSO networks meet the EPFD limits in Article 22.2 of the Radio Regulations;
- **Visualyse Spectrum Manager:** a product that can automatically analyse interference between terrestrial communications systems within a liberalised spectrum management regime.

Transfinite consultants can provide services such as training, coordination, sharing studies & other interference analysis, system radio planning & optimisation, and regulatory & licensing support.