INTERNATIONAL TELECOMMUNICATION UNION

ITU WORKSHOP ON MARKET MECHANISMS FOR SPECTRUM MANAGEMENT

Geneva, 22-23 January 2007

Document: MMS/05
January 2007

SPACE-CENTRIC MANAGEMENT

A General Solution for Equitable Access to Radio Spectrum Space under Conditions of Flexible Use

MICHAEL WHITTAKER

TABLE OF CONTENTS

FIGURES

1. INTRODUCTION

The purpose of government administrations providing industry with flexible access to parts of the radio spectrum is for the community to benefit from the ensuing competition derived from innovation in the provision of wireless services. Before investing in innovation, industry first needs the long-term certainty of, and clear rules for, flexible spectrum access. At a technical level the spectrum management model, self-managed or centralised, is not relevant.

Radio spectrum is multi-dimensional. Any specific part of the radio spectrum consists of not only a frequency band, but also a spatial volume (a geographic area and elevation plus height above ground) as well as a time period, five dimensions in total. Managing a number of interference mechanisms across multiple spectrum space boundaries under conditions of flexible access can be a complex task.

In practice, definition of flexible spectrum access rights has often not been ideal, their design by governments often driven by expediency and/or traditional spectrum management approaches. The main design weakness relates to the level to which negotiation is relied upon in order to take account of:

- partially defined spectrum access rights which do not provide a clear basis for the unambiguous settlement of interference resulting from the action of **all** interference mechanisms;
- spectrum access rights based on parameters related to only a subset of technologies and services[1]; and
- spectrum access rights which are not clear or legally robust.

While governments create spectrum licences containing these weaknesses it is industry which must then try to utilise them after purchase through an auction, award or trading process. The hoped for level of market-driven innovation never eventuates because industry belatedly finds there is:

- no preservation of inherent licence utility and hence licence value when dissimilar technologies and services are operated by other licensees in adjacent spectrum spaces; and
- reduced capacity for innovation caused by costly, uncertain and protracted negotiation with adjacent licensees and a Regulator for the management of interference.

2. COOPERATION IN EUROPE FOR INTRODUCTION OF FLEXIBLE SPECTRUM ACCESS

Cooperation between neighbouring countries in Europe for the introduction of flexible radio spectrum access has been slow because of the increased complexity in which radio interference would spill over country borders and frequency boundaries. Spectrum utility is limited by the manner in which guard areas and guard bands are designed to manage interference. Countries wish to ensure the full economic value of their radio spectrum space is either retained for use by their own population or, when necessary, at least shared in a manner that is both equitable and transparent.

Cooperation has occurred in the past through technical necessity arising from the operation of broadcast and cellular services. For both these services, the arrangements have been based on traditional broadcast

[1] Ignoring the type of information content, the term *service* usually also refers to equipment deployment. Certainly, the different ITU service categories, for example, "broadcasting service", "fixed service" and "mobile service" each infer a different type of equipment deployment within the frequency, spacial and time dimensions of radio spectrum space. In this paper, the term ***service*** refers to equipment deployment, for example, the actual carrier frequency (frequency); the location and effective antenna heights of transmitter and receiver (spacial); and the duplex mode or type of communication circuit employed (time). Therefore the term ***technology*** refers to equipment characteristics which are independent of deployment (for example, modulation, bandwidth, maximum data throughput, transmitter power, receiver sensitivity etc).

planning techniques. A requirement for cooperation in flexible spectrum access is now being driven by economic necessity, but simply extending old and familiar methods of interference management is not going to provide an equitable or indeed, cost-effective solution.

Spectrum access rights for PCS licences in the USA allow flexible use but have not been carefully designed. Licensees are subjected to non-reciprocal spectrum access when dissimilar technologies and services are operated [1, 2, 3, 4, 5]. Rephrased: "leads to inequitable spectrum utility in adjacent countries under conditions of flexible use". The necessary elements of a legal and technical framework to support flexible spectrum access in Europe must start with a careful reassessment of the suitability of current management practices.

There are two important requirements when managing flexible access to radio spectrum space:

- the utility of spectrum space must be **clearly defined** in relation to flexible use; and
- the utility of that spectrum space must be **preserved** no matter what type of technology or service is being operated in adjacent spectrum space.

The most important feature determining the ability of a spectrum market to improve efficiency is the manner in which the product being marketed (the utility of a spectrum space) is defined. Economic surmising about the benefit to a licensee of having maximum possible autonomy to determine the highest valued use of a spectrum space will come to nothing unless the access rules are clear and certain. The utility of the spectrum space must be first fully defined and then preserved. The opportunity for innovation is not found in generalisations about how the economy might perform given some abstract notion of technology and service-neutral access, but in the level of autonomy actually found in the spectrum access rules.

3. THE *SPACE-CENTRIC* APPROACH

Many of the proposals in an address by Commissioner Reding in Brussels earlier this year [6], parallel Australia's evolutionary move over the last 12 years from technical coordination (device-centric) to a coherent spectrum policy approach (space-centric) management. While the political complexity of Europe may tend to limit scope for Europe's evolutionary process, a tried and proven method for the flexible introduction of innovative new technologies and services is available, which is applicable to Europe and has been successfully used for the past 9 years. For the first time, reference [7] clearly describes the space-centric method as a fully scalable general solution for radio interference management in a flexible usage context.

While the space-centric approach utilises traditional device-to-device coordination, that is, explicit receive rights as legal requirements for protecting whatever legacy services must continue to be protected, it completely **reverses** the old management approach for the introduction of new services by employing explicit transmit rights (meaning receive rights are then implicit) based on clear and legally robust, interference benchmarks pertaining to **all** interference mechanisms. In addition, in order to preserve the utility of each spectrum space, the benchmarks are not constraints but reference points for the mandatory supply of specific amounts of internal guard band and guard area for any new equipment that exceeds the transmit rights.

Centralised management means that the Regulator performs both regulatory and spectrum manager tasks. Hence, centralised management naturally draws the attention of a Regulator, acting as a spectrum manager, to receiver protection and this is both reflected and supported by a type of explicit receive right: the long standing ITU concept of "harmful interference" (*that which seriously degrades, obstructs, or repeatedly interrupts a radiocommunications service operating in accordance with Radio Regulations*). In a sense this concept of interference has been the driver for the enormous effort in the production of device-to-device coordination procedures by Regulators, especially in Europe.

3.1 Explicit Transmit Rights: A Different Concept of "Harmful Interference"

There are a considerable number of benefits that can be derived from an alternate definition for "harmful interference" based on the other end of the transmit-receive communication entity: the transmitter. Under an alternate definition, "harmful interference" is defined as radiating greater than a specified maximum power, and this is without any concern for what level of interference any nearby receivers may experience. In other words, receivers are no longer treated preferentially but must be designed to work around deployed transmitters. Thus space-centric management is founded on *transmitter spectrum denial* (transmitters deny receivers access to spectrum) rather than *receiver spectrum denial* (receivers deny transmitters access to spectrum), which is the foundation of device-centric management.

Of course it is not exactly true that under space-centric management transmitters are deployed without concern for receivers. Transmitter deployment and the allowed maximum radiated power are both constrained in relation to the size of the spectrum space in which the transmitter is to be authorised to operate[2]. Neutral definitions for radiated power complete the new paradigm. Management of interference then moves from being device-centric to being space-centric as well as being technology and service neutral. Interference is managed by the operators of receivers who take account of the defined interference potential in their spectrum space resulting from fully defined transmit rights for transmitters operating in adjacent spectrum spaces. Authorisation to operate within a space, and frequency coordination of receivers within that space, become quite separate tasks instead of being integrated under the traditional device-centric method.

This is a different approach where transmitter authorisation is dependent on the size of the spectrum space that may be accessed. The basic commodity being managed becomes specified amounts of spectrum space which may be then traded or shared under agreements. A space-centric approach makes it possible to perform credible interference studies in advance of the deployment of new technologies and services and provides equitable spectrum access. Used generally, it can provide a transparent, fair, and stable interference management framework for independent evaluation of spectrum trading and flexible spectrum use, country by country. After careful analysis, space-centric management reveals many wide-ranging benefits for both industry and Regulators for facilitating market management.

4. INTERFERENCE CATEGORIES

Stakeholders in spectrum management come from many fields; politics, economics, law, engineering, manufacturing, infrastructure and social, and much published material on market mechanisms displays a misunderstanding of the potential usefulness and hence value of the spectrum space product. To enable the benefits of space-centric management to become reasonably clear to all stakeholders, the following is a simplified description of all the interference mechanisms that are able to affect the value of a spectrum licence. All these interference mechanisms require practical benchmarks so that potential licensees can establish the correct value of a spectrum licence.

Interference if often referred to broadly as harmful, unacceptable, excessive, undue, impermissible *etc*. Technically speaking, there are three main categories of interference (see Figure 1).

4.1 Interference Category A

Interference Category A is caused by a transmitter:

- usually located at a long distance from a receiver; and
- radiating high level emissions at frequencies that fall within the receive bandwidth.

This situation can be described as *same band-adjacent area* <u>in-band</u> interference and can occur throughout the total frequency band of a spectrum licence at locations that are near the geographic boundary.

[2] The device-centric focus on receiver protection has been accompanied by few if any, space related constraints on the deployment of transmitters (except perhaps using transmit groups of channels in different geographic areas).

4.2 Interference Category B

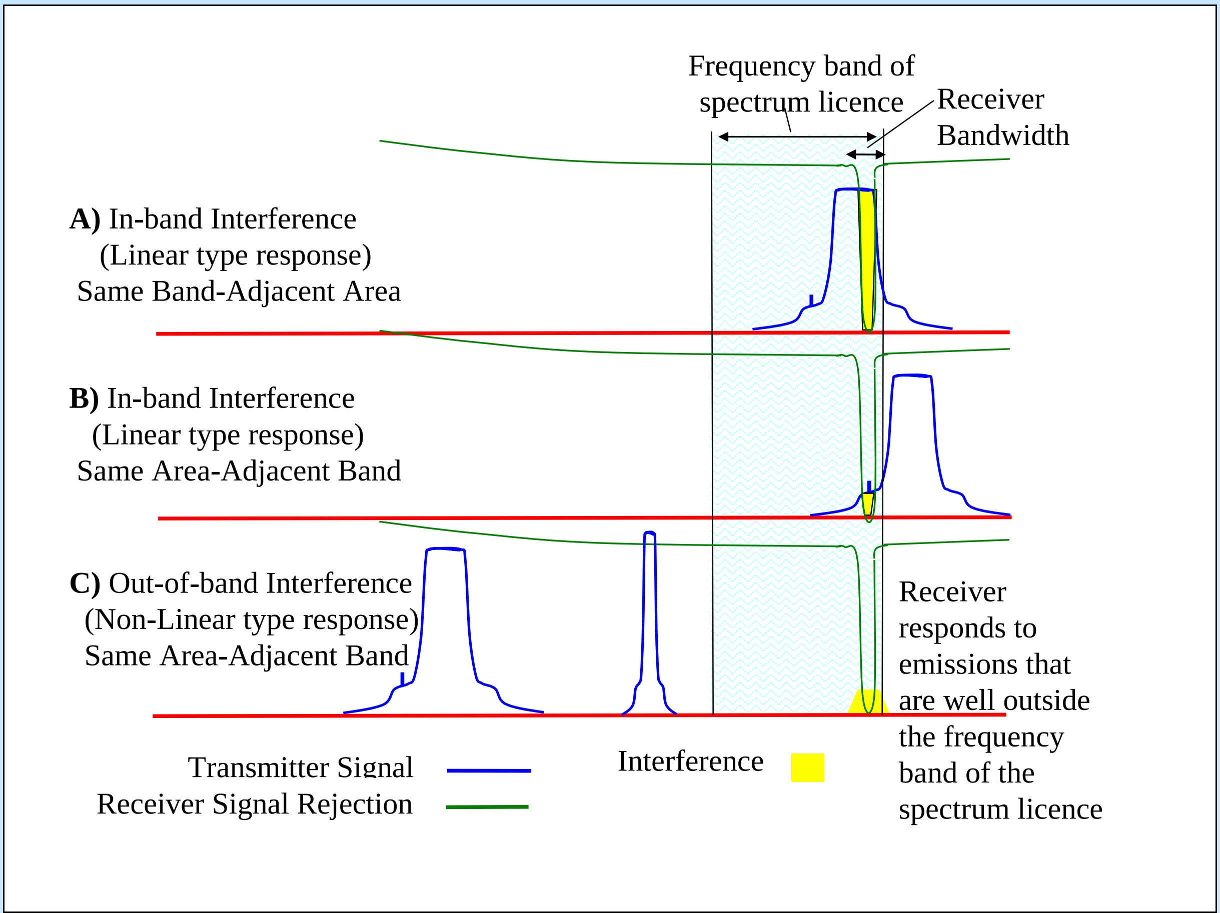
Interference Category B is caused by a transmitter:

- located at a short distance from the receiver; and
- radiating low level emissions at frequencies that fall within the receive bandwidth.

This situation can be described as *same area-adjacent band* in-band interference and can occur throughout the total geographic area of a spectrum licence at frequencies that are near the frequency band limits.

Category B is especially significant when wideband equipment is operated and only one channel can be contained within a spectrum licence

Figure 1: The three categories of interference in relation to a spectrum licence



4.3 Interference Category C

Interference Category C is a non-linear type of interference where the unwanted signal power does not simply add to the receiver noise in a one-for-one manner but can create a much higher level of unwanted power in the receiver.

Interference Category C is caused by the receiver responding to the radiated emissions of one or more transmitters:

- usually located at a short to medium distance from the receiver; and
- operating at frequencies outside the receive bandwidth (see Figure 1). These frequencies can be well outside the receive bandwidth for interference to still occur.

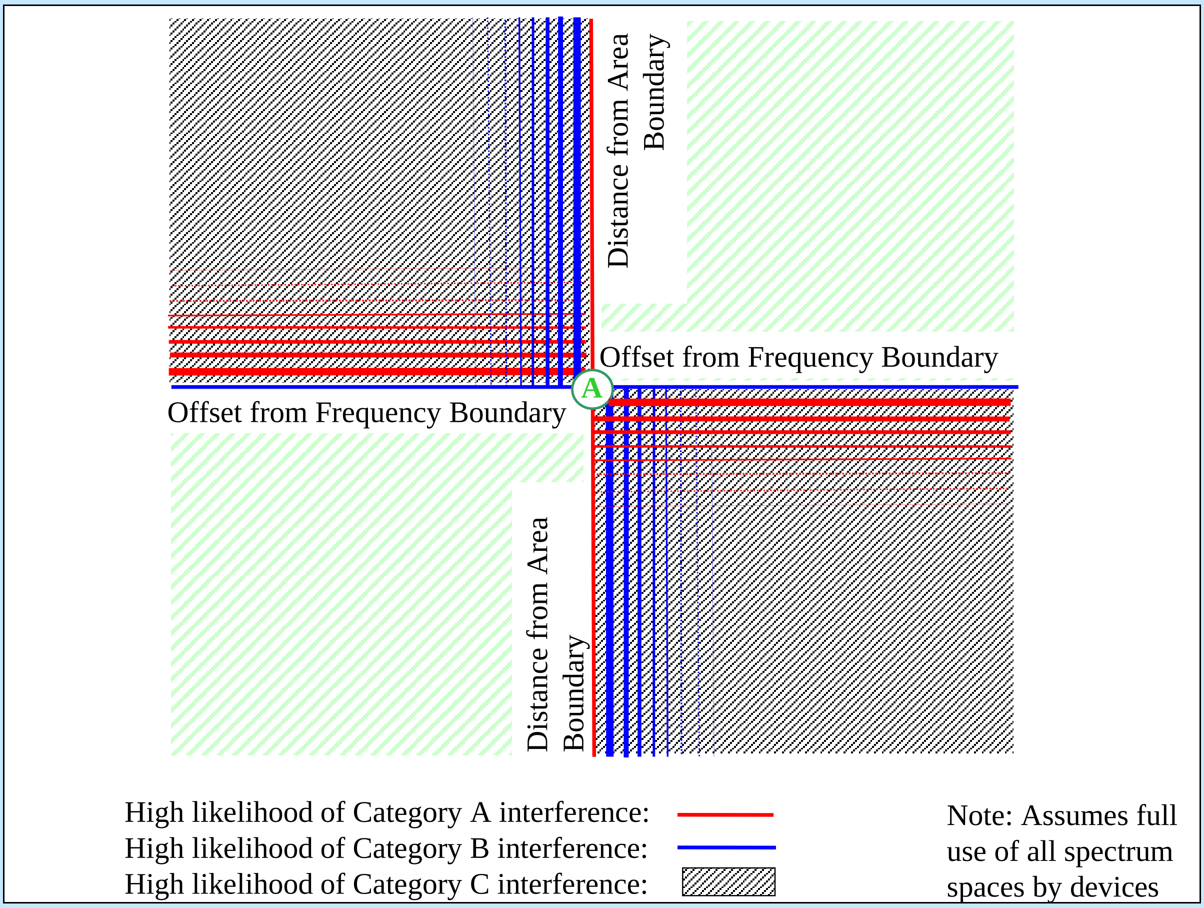
The receiver can have a number of interference responses, one of which is intermodulation where there is production of discrete new interfering signals at new frequencies by the receiver's electronic circuitry. These responses are caused by the non-linearities in the receiver's physical implementation. The interference level depends on receiver design and construction quality but can not be completely avoided.

Category C interference can be described as *same area-adjacent band* out-of-band interference. Depending on device locations, it can occur throughout the total geographic area and the total frequency band of a spectrum licence. The likelihood of Category C interference is much greater than A or B[3] and because of its high interference potential, Category C interference must continue to be managed under flexible spectrum access just as it needs to be carefully managed under traditional licensing methods.

5. Pictorial Representation of Interference between Spectrum Spaces

Parts of spectrum space can be adjacent in relation to each of its five dimensions. Figure 2 represents the likelihood of each of the three interference categories in relation to a "point of spectrum space adjacency" represented as the origin of a graph, shown as the following symbol:

Figure 2 : Illustration of the likelihood of the three categories of interference



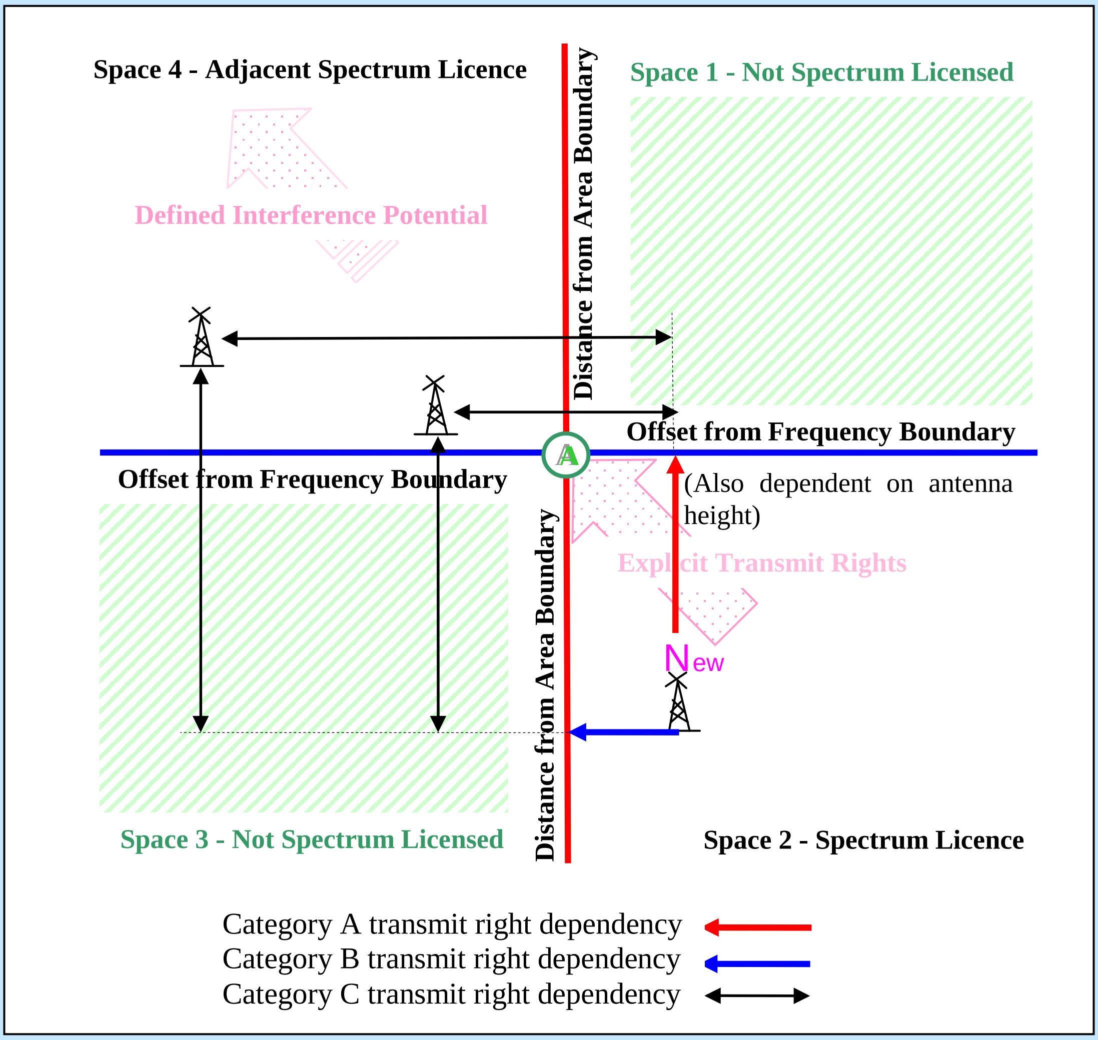
[3] Note that emissions from a transmitter can cause interference categories B and C in the same receiver simultaneously.

The origin represents any single point on the multi-dimensional boundaries of spectrum space. Multi-dimensional spectrum spaces have continuous adjacent boundaries but this diagram represents only a single point of interaction between them. Each quadrant represents a separate spectrum space which would be managed under one form of licensing. Note that all four quadrants could be spectrum licensed. In each quadrant, increasing separation from the symbol represents a device having increasing frequency offset (the horizontal axis) and distance (the vertical axis) from the point of spectrum space adjacency[4].

6. INTERFERENCE BENCHMARKS FOR *SPACE-CENTRIC* MANAGEMENT

Each interference category has a different likelihood of occurrence and so transmit rights must be established which separately take account of each category, and when necessary, each interference mechanism within each category. A transmit right that is used to manage a particular interference category is made up of a number of *interference benchmarks.*

Figure 3: Some transmit right dependencies for a New transmitter



[4] There is a possible third axis perpendicular to the page. This could be used to represent a number of other parameters including time.

Because transmit rights and their interference benchmarks define interference potential in adjacent spectrum spaces, the maximum allowed radiated power for a new transmitter that is to operate within a spectrum space depends, *inter alia* (see Figure 3):

- in the case of linear type interference, on:
  - antenna height and distance from the area boundary (Category A);
  - offset from the frequency boundaries (Category B); and
- in the case of non-linear type interference, on:
  - distance and frequency separation from devices operating **outside** the space (Category C).

6.1 Practical Benchmarks for In-band Interference

Interference categories A and B are both in-band interference in the sense that unwanted emissions from transmitters fall directly within receive bandwidths (see Figure 1).

The related interference benchmarks should not be defined as conducted power, measured where the transmitter connects to an antenna, but as clear and easily verifiable limits for radiated power. Radiated power limits maximise implementation flexibility and are more closely related to interference potential. Furthermore, benchmarks must be established with respect to the level radiated from a single antenna or single antenna array because, in practice, a number of transmitters may be coupled to the same antenna. In this case individual transmitter emission levels would add together, and could easily exceed the benchmark if it was defined with respect to a single transmitter. A similar situation also occurs with a single transmitter operating with multiple carrier frequencies.

6.1.1 Category A Benchmark

Category A interference is more likely when devices are near a geographic boundary. A licensee's transmit right in these circumstances should be clearly defined in a technology neutral manner and, to increase efficiency, should take account of any terrain shielding existing **within** the licence geographic areas. The concept of a "*device boundary*" is useful to simplify Category A management where transmission may be authorised when the relevant boundary, based on the power the device radiates in all directions, is fully contained by the geographic area of the spectrum licence.

For the design of the device boundary there is only a broad choice related to whether protection is to be provided to area-adjacent services operating at:

- high and low elevations; or
- just low elevations.

The device boundary criterion should not be viewed as a model for coverage or service area. It is a clearly defined transmit right, independent of what levels may actually occur on, or past a geographic boundary. The primary objectives when designing the device boundary criterion are:

- to establish a single, clear and legally robust rule for the transmit right and thereby, the settlement of Category A interference without difficulty including without legal intervention; and
- for wireless network design purposes, inform area-adjacent spectrum licensees of the maximum level of in-band power that can be radiated in a particular direction from a particular site at any time during the licence period so that those licensees may act to protect their receivers.

Secondary objectives when designing the device boundary criterion are:

- to allow area-adjacent licensees to establish services as close to the common geographic boundary as possible without having to resort to the cost and uncertainty of negotiation; and
- if negotiation turns out to be necessary, set a clear starting point from where negotiation may progress.

Licensees use the device boundary criterion as a starting point for their proprietary coordination procedures, which include high resolution propagation models of their own choice, to establish the necessary level of receiver protection from interference caused by transmitters in area-adjacent licences.

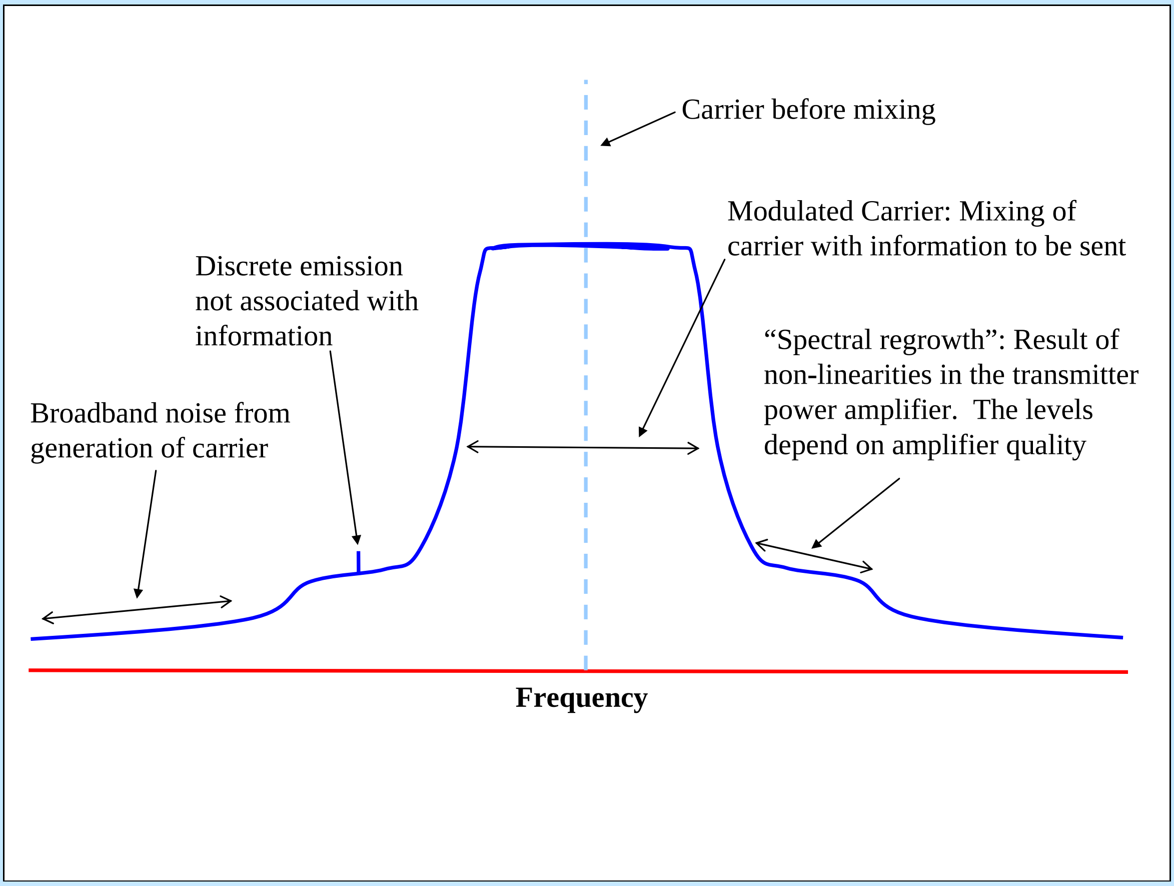
6.1.2 Category B Benchmarks

Category B interference can occur when a transmitter has out-of-band emissions falling within the frequency band of a frequency-adjacent licence[5]. These emissions are usually a byproduct of information transmission and can be steady-state or transient (see Figure 4) as well as:

- being frequency discrete; or
- having broadband characteristics.

Discrete and broadband emissions have different likelihoods of frequency coincidence with a receiver and therefore, they are usefully assigned different radiated power limits. Note that any type of emission from a transmitter that is authorised under a spectrum licence and falls within the frequency band of that licence, does not have to be checked against transmit rights pertaining to Category B interference.

Figure 4 : Components of a transmitter emission



Broadband transmitter emission related to Category B interference includes:

- "spectral regrowth" of the modulated carrier caused by transmitter amplifier non-linearities;
- transients which arise, for example, when a transmitter is switched on or off and the fall or rise in radiated power spreads emission over a large bandwidth, the size of which depends on the speed at which the switching occurs; and
- broadband noise, which normally arises from the electronic circuitry used to generate the carrier signal of the transmitter.

[5] The term "block" is occasionally used as in "out-of-block emissions". The term is superfluous as well as confusing, "frequency band" or "band" being much more meaningful.

In practice, limiting three types of radiated power outside the frequency band of a spectrum licence is necessary in relation to the management of Category B interference:

- average broadband radiated power;
- peak radiated power; and
- average discrete radiated power.

Note again that the limits for maximum out-of-band emission are a clearly defined transmit right which frequency-adjacent spectrum licensees must take into account when operating receivers.

6.2 Practical Benchmarks for Out-of-Band Interference

Out-of-band interference should not be confused with the interference caused by out-of-band emission discussed in the preceding section.

There are four main ways in which a transmitter(s) can cause Category C (out-of-band) interference in a receiver:

- selectivity;
- blocking;
- spurious response; and
- intermodulation.

6.2.1 Elements of a Receiver

Figure 5 is an illustrative depiction of most receivers in use today; the heterodyne receiver, invented by Edwin Armstrong in 1918 and which operates over a range of radiofrequencies but demodulates them at a constant (intermediate) frequency. A receiver normally utilises Radio Frequency (RF) and Intermediate Frequency (IF) filters and both affect its susceptibility to in-band (Categories A and B) as well as out-of-band (Category C) interference. The RF filter is the very first receiver component and it reduces the level of signals outside that filter's pass band. Any signals within its pass band are amplified and then mixed with another signal, called the Local Oscillator (LO), to convert a received signal into a single lower intermediate frequency. The LO signal is not spectrally pure and includes broadband (phase) noise and discrete spurious harmonic signals. When the mixing occurs these implementation imperfections create additional signals that can interfere with the wanted signal.

A second filter, a narrowband IF filter, then passes, the frequency-converted wanted modulated signal plus any interference, to the demodulator where the transmitted information is recovered. Frequency conversion provides a number of benefits including frequency stability and ability to take advantage of the ease of manufacture of very good quality narrowband filters at low frequencies. The shape and width of the IF filter significantly affects the final quality of the recovered signal.

Receiver Selectivity

An unwanted transmitted signal causes Category C interference in a receiver, of a type referred to as selectivity, when it creates a noise-like signal within the IF pass band of the receiver, through reciprocal mixing with the broadband noise of the receiver's local oscillator signal.

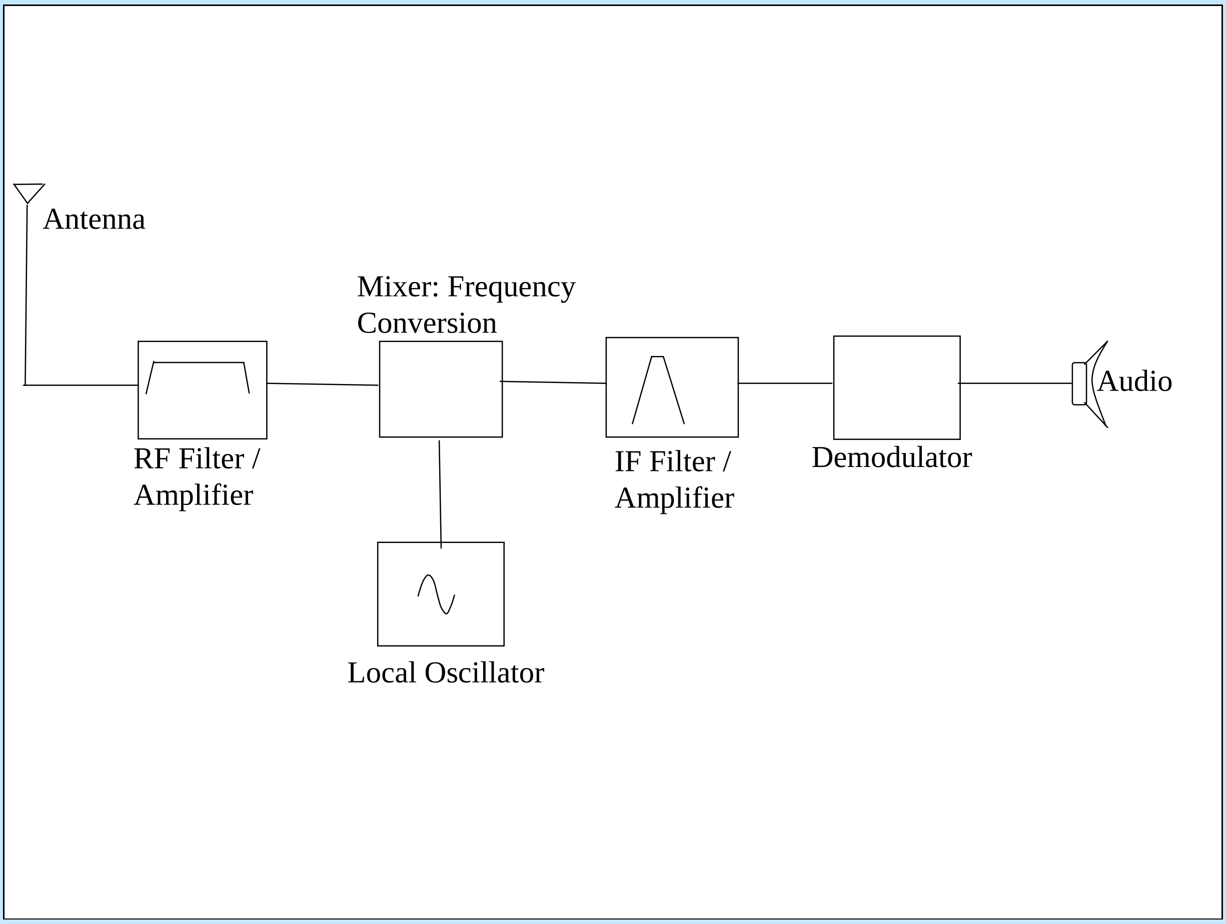
Receiver Blocking

An unwanted transmitted signal causes Category C interference in a receiver through blocking when it sufficiently overloads the receiver input amplifier or mixer stages to change their normal operating mode. This type of interference is not the same as that involving receiver selectivity, although both can sometimes occur simultaneously for small, unwanted signal frequency offsets.

Receiver blocking impacts most on co-located transmitter-receiver operation. The transmitter-receiver configurations necessary to avoid blocking depend on the maximum allowed transmitted power, RF filter characteristics, and achievable isolation between co-located antennas.

Receiver Spurious Response
An unwanted transmitted signal causes Category C interference in a receiver through spurious response when the unwanted signal is at a characteristic frequency, usually greater than 3 MHz from the receiver's operating frequency. Spurious response immunity is largely a function of the RF filter characteristics, RF amplifier tuning, spectral purity of the LO, and most importantly, the frequency chosen as the IF. A LO frequency that is higher than the wanted signal creates fewer spurious responses than one which is below. Furthermore, it is possible to optimise the choice of the LO frequency to minimise the number of responses.

Figure 5: Illustrative depiction of a receiver



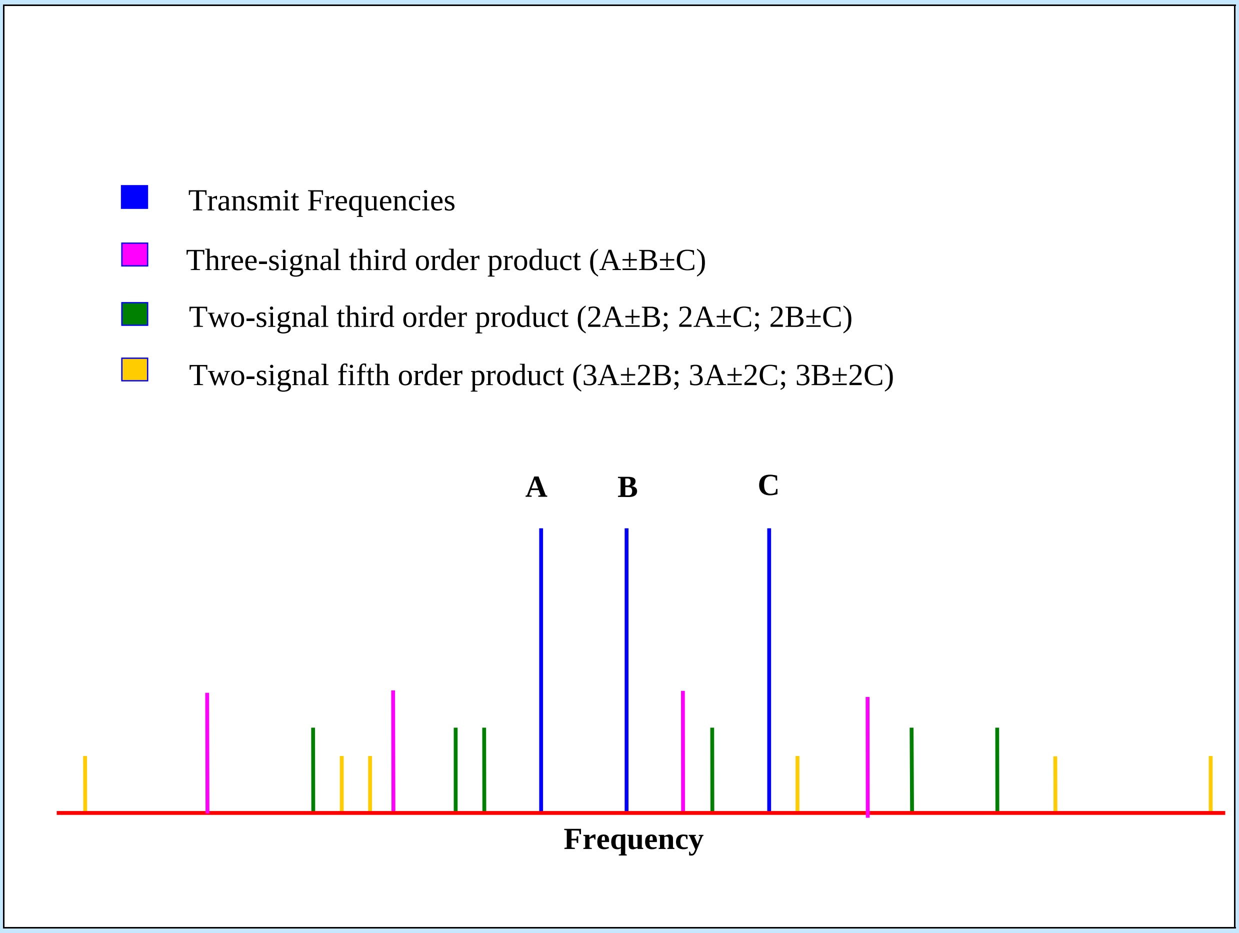
Receiver Intermodulation
There is no close parallel to intermodulation in the management of any other natural resource.

Transmitters cause Category C interference in a receiver through intermodulation when the radiated power of two or more transmitters, with specific amplitude and frequency relationships to the wanted signal, are present in the receiver's input circuitry with consequent production of discrete new signals caused through mixing of the signals. The new signals are called intermodulation products. If the new signals have frequencies which fall within the IF passband they will interfere with the wanted signal. Different intermodulation products result from different combinations of signals as well as different orders of non-linearity. Two-signal third order, two-signal fifth order and occasionally three-signal third order intermodulation interference scenarios are usually checked as a precaution when assigning frequencies to co-located services (see Figure 6). Models for the conversion efficiency of each type of intermodulation product can be based on the non-linear characteristics of a semiconductor. These characteristics usually provide a very good approximation to actual receiver performance

In areas where there are many transmitters, receiver intermodulation interference can be both many times the power level and many times more likely, than the linear type of interference of categories A and B [8], so special account must be taken of receiver intermodulation in the design of spectrum access rules for flexible spectrum licensing. Many transmitters located together create a veritable "forest" of intermodulation products each of which, given the right circumstances, can cause interference.

Intermodulation interference results from the operation of any type of transmitter and receiver including mobile devices. For base stations with line-of-sight propagation conditions, intermodulation interference can occur over distances up to 20 km [9]. In 1967, Pye Proprietary Ltd described the prevalence of receiver intermodulation interference for single-frequency land mobile radio base stations as on the verge of "becoming insoluble"[10]. Intermodulation interference can be restricted to co-located devices but only through using special technical solutions. Interference benchmarks must still be established to support the design of those solutions.

Figure 6: Intermodulation Products



Base station receivers are fitted with RF filters which can help manage intermodulation interference. FDD two-frequency services usually have a broad, low roll-off RF filter with a passband consistent with the bandwidth over which the grouped base receive channels operate. Receiver intermodulation interference can be a problem when fixed or mobile transmitters operate within or near that passband. Depending on the characteristics of the filter, it is possible for transmitters separated by up to tens of MHz from the receive frequency to cause problems. Under conditions of high spectrum use, the effective capacity of a CDMA channel has been shown to be substantially reduced due to the effects of intermodulation interference in base station receivers from frequency-adjacent mobile transmitters [11]. In the case of TDD single-frequency services, because they always operate with directly adjacent base transmitters and mobile transmitters, a separate high performance base receive RF filter is required for each channel.

The high levels of spectrum utility envisioned for future dynamic spectrum access will only be achieved through proper management of intermodulation interference. For example, intermodulation orders involving only two transmit signals are typically now assessed during coordination of base stations because the likelihood of more than two transmitters operating simultaneously is currently low. This will no longer be the case for high level dynamic access where many transmitters are intended to operate simultaneously.

6.2.2 Category C Benchmarks

Category C interference is the most difficult to manage for flexible spectrum access. Managing it with fixed radiated emission limits is impractical because of its non-linear nature and a more complex radiated power limit must be used for the related transmit right.

For a transmitter operating within a spectrum space, the maximum authorised level of radiated power in relation to this category of interference is found through application of a *model coordination procedure* for transmitters and receivers operating <u>outside</u> the licensed spectrum space. The model coordination procedure is based on:

- benchmarks for each of the out-of-band interference mechanisms in a receiver: essentially a level of isolation related to each interference mechanism for unwanted signals at specific frequency offsets:
  - selectivity;
  - blocking;
  - spurious response; and
  - intermodulation (must include a model for calculating the level of significant intermodulation orders);
- a notional receiver:
  - RF filter characteristics (passband consistent with licence band);
  - IF filter characteristics;
  - compatibility requirement for the four interference mechanisms;
- a propagation model;
- first-in-time policy and centralised database of existing devices; and
- device deployment constraints that define the situations in which the model coordination procedure is to be applied.

The practical effect of application of the coordination model is to clearly define transmit rights relating to Category C interference. The notional compatibility requirement should not be viewed as an explicit receive right. Application of the model also provides a simple yes/no criterion for determining which licensee is causing interference and consequently, who is responsible for its settlement.

6.3 Additional Interference Benchmarks for *Space-Centric* Management: Deployment Constraints

Traditionally, the term "service" relates not only to the type of information content being transmitted but also the manner in which equipment or technology is deployed within the frequency, spacial and time domains of radio spectrum space. A particular method of deployment creates a certain level of inherent guard space which affects interference likelihood. Therefore, the transmit rights must also contain elements to define an inherent guardspace. These elements consist of deployment constraints and result in optimisation of the transmit rights for a particular general service type because different general service types utilise different types of deployment. The constraints relate to particular interference mechanisms and modify the interference potential in adjacent spaces. They form part of the interference benchmarks for transmit rights in both a technical and legal sense.

The constraints are:

- allowed range of transmitter effective antenna heights plus complementary rules that specify when the model coordination procedure for Category C interference management is to be applied;
- additional limits for maximum radiated power for transmitters used in certain circumstances;
- situations in which transmitters must use directional antennas;
- collision avoidance benchmark that defines when a number of transmitters may be authorised as a group;
- co-location benchmark for defining when a licensee is responsible for management of interference between all devices; and
- minimum licence bandwidth as a basic support for the design of the transmit rights.

More details can be found in reference [7].

7. BENEFITS OF *SPACE-CENTRIC* MANAGEMENT FOR MARKET MANAGEMENT

For market management, the roles of Regulator and spectrum manager become separated. Market management shifts regulatory attention from the micro-management of protection for individual receivers to the provision of a broad legal and technical basis for independent interference management by the industry spectrum manager. A shift of this nature can be supported to quite a surprising level by using an alternate definition of harmful interference incorporating explicit transmit rights.

Explicit transmit rights make it practical for industry (a spectrum licensee) to take over the design of coordination procedures for management of a given spectrum space, because it becomes a case of managing interference **from** an adjacent spectrum licensee instead of managing interference **to** another spectrum licensee. Managing the uncertainty associated with propagation is shifted from the operators of transmitters to the operators of receivers. This change is significant because in a self-management regime, licensees are able to accept higher risk when the outcome only affects their receivers, thus avoiding the traditional spectrum-inefficient risk-averse approach. Importantly, negotiation for interference management is then minimised. However, if negotiation ever becomes necessary the benchmarks provide very clear starting points. Explicit transmit rights also does away with the very costly time-consuming and unsatisfactory process of interference settlement through radio monitoring. Thus explicit transmit rights facilitate interference self-management.

7.1 Dynamic Spectrum Access

Under market management, the separated roles of Regulator and spectrum manager result in separation of the processes of device authorisation and device coordination. The authorisation process for space-centric management takes account of the size of the spectrum space in which equipment is to operate and without any dependence on equipment standards. It does this by having rules which clearly separate authorisation for a device to operate within a defined spectrum space from coordination to manage interference between authorised devices. For centralised management, authorisation and coordination are usually part of the one process.

The separate steps of authorisation and coordination for flexible spectrum licensing make it ideal for spectrum management by countries which have common geographic boundaries as well as for the authorisation of software reconfigurable devices in those countries. It is possible that “smart” or cognitive radios which sense and assess the interference environment may eventually automate authorisation and coordination for devices using high transmitter power and operating within a spectrum commons. Nevertheless, while authorisation might become automated, the spectrum access rules defining that authorisation process can be provided through space-centric management.

8. CONCLUSION

Application of market mechanisms to spectrum management requires full definition of the value/utility of the spectrum product. In addition, the utility of the spectrum space must be preserved meaning that for flexible spectrum access, clear and certain benchmarks must be set in relation to **all** interference mechanisms and spectrum access rules must incorporate use of internal guardspace when necessary. Centralised (device-centric) management has functioned with a concept of interference as explicit receive rights ("harmful interference") but flexible (space-centric) management requires a concept of interference as explicit transmit rights. Space-centric management allows radio spectrum space to be treated as a commercial asset with a clearly defined utility under conditions of flexible use where technology and service can be determined by industry. The access rules can then preserve a level of utility for the spectrum space which continually reflects its commercial value. This is achieved by directly managing interference in relation to the size of a spectrum space rather than applying indirect management through equipment standards. When correctly designed, space-centric management minimises costs associated with negotiation, uncertainty and involvement of the Regulator. A broad comparison of device-centric and space-centric spectrum management is given in the Appendix.

REFERENCES

[1] See Telecommunications System Bulletin TSB-84A Licensed PCS to PCS Interference, Telecommunications Industry Association, USA

[2] See for example, "*Although PCS providers are licensed by the FCC, there are only minimal FCC rules in place that address interference between service providers. The minimum performance requirements specified by the industry standards either mimic FCC requirements, or are liberal so as not to provide any practical level of interference protection*." from "*STOP Interfering*" by Andrew W. Clegg, September 2000 at *http://telephonyonline.com/wireless/ar/wireless_stop_interfering*.

[3] See comments on the impractical nature of the FCC condition requiring "*The predicted or measured median field strength at any location on the border of the PCS service area shall not exceed 47 dBmV/m*" in the NSMA recommendation "*Inter-PCS Co-Block Coordination Procedures*" National Spectrum Managers Association, Recommendation WG 20.97.048, Rev. 1.0, January 1999.

[4] See comments in Hatfield, D.N.; Weiser, P.J "*Property Rights in Spectrum: Taking the Next Step*" First IEEE International Symposium on New Frontiers in Dynamic Spectrum Access Networks, DySPAN 2005. 8-11 Nov. Page(s):43 – 55, relating to why the over-simplified out-of-area emission limits have worked for the particular situation of PCS but do not provide a workable solution in general.

[5] "*Some industry stakeholders and panelists indicated that FCC should better define the rights accompanying spectrum licences, as these rights can significantly affect the value of a licence..*" See "*Options for and Barriers to Spectrum Reform*" US Government Accountability Office (GAO), March 2006, GAO-06-526T.

[6] Reding V. "*Reaping the full benefits of a more coherent European approach to spectrum management*" European Spectrum Management Conference, March 2006

[7] Whittaker M. "Flexible Radio Spectrum A*ccess: Moving from Device-Centric to Space-Centric Management*" Edition 1.0, March 2006 available at *www.futurepace.com.au*.

[8] The increase in the number of intermodulation products in relation to the number of primary transmitted frequencies is exponential. Special algorithms must be used for large number of transmitters in order to calculate these products with a computer in reasonable time periods – see for example, the Difference

Triangular Matrix Method of Steiner J.W. "*An analysis of radio frequency in interference due to mixer intermodulation products"* IEEE Trans. on EMC Vol 6, N. 1 January 1964.

[9] Jim West, Summitek Instruments USA, private communication, September 2006: "*The consensus around the office is that the fundamental question should be, 'How far away can a transmitter actually be and still cause intermodulation interference (IM)?' The answer will depend on a variety of factors: Output power of the "suspect" emitters, IM order, path loss, frequency and the mechanism of the intermodulation mix. Most of the interference issues we have resolved have been situations where the "suspect" emitters generating the interference have been* ***within a few miles of each other****. In a few rare cases, we have seen interference from a very high power broadcast station over 15 miles away contribute to an interference problem at a base station*".

[10] deVille G. "*Interference in V.H.F. mobile radio systems*" Pye Proprietary Ltd., Melbourne, Victoria, Radio and Electronics Engineering Convention, Sydney May 22-26, 1967 pgs 190-191.

[11] Bundy S.C "*Quantifying the Benefits of Enhanced Filter Selectivity*" IEEE Microwave Magazine, June 2003 pp 48-59.

ABOUT THE AUTHOR

Michael.Whittaker@futurepace.com.au, B Sc. (Physics), Grad. Dip. Electronics, has over 22 years experience in radio spectrum planning, working for the Australian Government beginning 1984, pioneering automated frequency assignment systems and publishing in that field. Michael led the introduction of flexible spectrum management techniques in Australia in 1994 becoming the principal architect of the form of flexible spectrum licensing which supports either the outsourced or centralised regulatory authorisation of spectrum access for any type of technology and service through compliance with either a fully defined set of explicit transmit rights in relation to all interference mechanisms, or provision of any necessary internal guard space based on those rights. This is a space-centric approach which can provide equitable spectrum access when dissimilar equipment is operated in adjacent spectrum spaces. It can also create practical rules for authorising dynamic spectrum access by software reconfigurable devices.

Michael was chairman of the Technical Liaison Group in 1997, a Government sponsored industry consultative forum which established the licence conditions for 800 MHz and 1.8 GHz spectrum licences. Michael also later designed the 28/32 GHz and 3.4 GHz spectrum licence conditions and is now a director of FuturePace Solutions designing web-based online transmitter certification and authorisation services for outsourced self-management of interference, incorporating automated compliance and coordination checks as well as the integration of real time EMF/EMR human exposure management for complex shared sites at which those transmitters operate. Michael authored a book "*Flexible Radio Spectrum Access*" in 2006 which for the first time clearly described the space-centric method as a fully scalable general solution for radio interference management in a flexible usage context.

Appendix – Comparison of Device-Centric and Space-Centric Management

Device-Centric Spectrum Management (*e.g.* Apparatus Licensing and Harmonised Spectrum Licensing)	**Space-Centric Spectrum Management (*e.g.* Flexible Spectrum Licensing)**
Allocation of part of the spectrum (frequency band, geographic area and time) for use by devices that comply with mandated equipment standards (similar technologies and one general service type).	Allocation of parts of the spectrum for use by any technology and service, including dissimilar services
Takes account of emissions "spilling" outside the dimensions of the spectrum space implicitly or through negotiation.	Takes account of emissions "spilling" outside the dimensions of each spectrum space explicitly and without any need for negotiation
Interference management based on *receiver spectrum denial*.	Interference management based on *transmitter spectrum denial*.
Radio interference between the devices is managed indirectly through the standards which enables coordination to take place against conventional rules.	Radio interference between spaces is managed directly
Equipment type approval certifies the laboratory "bench" performance of a device with respect to its standard	Equipment type approval certifies the radiated emissions of a device with respect to rules for access to a spectrum space
The process of type approval occurs before integrated processes of device coordination and authorisation	The two processes of type approval and authorisation are integrated and occur before device coordination
Equitable spectrum access is provided for each device but a nexus is created between device authorisation and standards	Equitable access is provided to each spectrum space and no nexus exists between device authorisation and standards
Standards are approved by Regulators who remain central to the authorisation process.	Regulators are usually completely removed from the device authorisation and coordination process
This approach hampers industry innovation.	This approach maximises opportunity for industry innovation by treating radio spectrum as a commercial asset with a clearly defined utility that is maintained for the full licence period