Spectrum Property Rights and Practical Auction Design:

The Australian Experience

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Abstract

The radiofrequency spectrum is a valuable national economic resource. Efficient use of this resource is important to national economic well-being.

National administrations have traditionally relied on a centrally planned model to manage spectrum. This has involved planning the use for parts of the spectrum at a national level, consistent with international conventions, and then issuing device specific licences following these plans. Allocation of these licences has traditionally involved a combination of "over-the-counter" allocation, ballots and lotteries, comparative merit assessment, and, more recently, price-based allocation.

As the pace of technological change increases, this traditional and widely practised approach is coming under increasing pressure. The time taken for national administrations to re-plan the use of spectrum for emerging new technologies can sometimes take longer than the life cycle of the technologies. This is especially true in the telecommunications sector.

A goal for many years has been to develop a system that brings market responsiveness to spectrum management, so that spectrum use can be changed in direct response to market conditions and the emergence in the market place of new technologies.

Australia has recently developed and implemented a property-like rights regime in radiofrequency spectrum, giving licensees unprecedented flexibility to buy and sell spectrum as a resource in an open market so that responses to technological change can be taken against a market setting.

This paper outlines Australia's general approach and its application of the technique.

Author’s Notes and Disclaimer

This paper refers extensively to the Spectrum Management Agency (SMA). On 1 July 1997, the SMA merged with elements of the former Australian Telecommunications Commission (AUSTEL) to form the Australian Communications Authority (ACA).

This paper records some of the work that led to the development of spectrum licences in Australia and is based on the personal experiences and observations of the author as manager of the development team.

The views expressed in this paper are those of the author and should not be taken to infer any endorsement by the former Spectrum Management Agency, the Australian Communications Authority, or the Australian Government.

An earlier version of this paper was presented to the 1997 Industry Economics Conference ***Making Competitive Markets***, on 10 to 11 July 1997 at the Melbourne Business School, University of Melbourne, Victoria. This paper has been revised to take account of suggestions received from colleagues on that earlier paper and has been updated to reflect the current position on spectrum property-like rights and auctions in Australia.

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Common Abbreviations in this Paper

ACA	*Australian Communications Authority*
AUSTEL	*Australian Telecommunications Authority*
BTCE	*Bureau of Transport and Communications Economics*
CRA	*Charles River Associates*
FCC	*Federal Communications Commission*
ITU	*International Telecommunication Union*
HORSCOTCI	*House of Representatives Standing Committee on Transport Communications and Infrastructure*
MDI	*Market Design Incorporated*
MDS	*multi-point distribution services*
PCS	*personal communications services*
RALI	*radiocommunications assignment licensing instruction*
SMA	*Spectrum Management Agency*
SMT	*Spectrum Marketing Team*
STU	*standard trading unit*

Introduction to Spectrum Management

Radiofrequency Spectrum

The radiofrequency spectrum is that part of the wider electromagnetic spectrum that can be used for radiocommunications, that is, communication by radio. The radiofrequency spectrum is at the low energy end of the electromagnetic spectrum. The electromagnetic spectrum also covers infrared radiation, light, ultra-violet radiation, X-rays and, at very high energies, gamma rays.

The ***Radiocommunications Act 1992*** (the Act) defines *spectrum* as

> *the range of frequencies within which radiocommunications are capable of being made*

The Act further defines a *radio emission* as

> *...any emission of electromagnetic energy of frequencies less than 420 terahertz without continuous artificial guide*

Because the radio emission is radiated freely (not guided), it must be managed, so that two signals with the similar or complementary characteristics cannot be received at a receiver at the same time. When two or more signals are available at a receiver at the same time, these signals can "interfere" with each other, and the information contained in the signals may be lost.

Coordinating spectrum use to avoid interference between signals has traditionally been done by national governments. Governments have controlled every level of the process, from international coordination at the treaty level, through national planning, individual band planning and ultimately to licence issue and administration. This approach has been cemented in history, and, while the traditional justification for such an approach is beyond the scope of this paper, it seems to have been widely accepted that management and planning of the spectrum is fundamentally a role of Government.

The Planning Process

Traditional radiocommunications planning and licensing is based on a hierarchical structure of planning powers contained in the Act. At the highest level, it involves Australia's participation in the international community, through the International Telecommunication Union (ITU). The ITU facilitates international agreement about how use of the spectrum will be coordinated to minimise the potential for interference between nations. The ITU is an organisation under the umbrella of the United Nations, and nations gain the benefit of the negotiated positions it develops by agreeing to be subject to ITU treaty obligations. The ITU's negotiation process is centred on the World Radio Conference, which takes place every two years.

At the next level of planning is the Australian Spectrum Plan (SMA, 1997), the central planning instrument under Australian law. This plan divides the spectrum in Australia between specific uses, for example, fixed services, mobile, broadcasting, satellite, defence, scientific and other uses. The Australian Spectrum Plan generally follows the assignment of spectrum developed in the international community, to which Australia accedes by treaty. The process for making and varying the Australian Spectrum Plan is typically protracted. Variations are subject to public consultation with affected users and this can take many months.

Band plans form the next level of the planning hierarchy. Band plans set out how a band identified for a specific use in the Australian Spectrum Plan will be managed. Band plans make provision for specific types of services, and establish a framework under which these types of services can be licensed. A Band Plan must be compatible with the Australian Spectrum Plan. Band plans are also prepared following a process of public consultation. While there is provision for making a band plan without consultation, the decision to do so would be hard to defend at law unless making the plan in this way was necessary for order and good government.

At the bottom of the spectrum management hierarchy are licensing plans and policies, articulated through instruments called Radiocommunications Assignment Licensing Instructions (RALIs). These are administrative instructions that codify operational practice about how licences can be assigned in particular bands.

Making provision of a new technology might typically involve:

- consideration in the international community of an appropriate band for the deployment of that technology which may take 2 or more years;

- consideration of whether and how to adopt the change in Australia, which may then lead to preparation of draft amendments to the Australian Spectrum Plan, and then public consultation on those amendments;

- following finalisation of the spectrum plan, preparation of a band plan, consistent with the spectrum plan, which makes provision for the new service, and sets out how incumbent users will be treated (for example, will the plan provide for non-renewal of existing licences?); and

- finally, once all the plans are in place, individual licensing of services, on a case by case basis, carefully coordinating the new services with any incumbents whose licence allows them to remain.

By the time this process has taken its course, it is possible that a newer and possibly better technology may be on the horizon. This effect is perhaps illustrated in the field of computing. The remarkably predictive “Moore’s Law” suggests that the logic density of a constant sized silicon chip will double every year. The convergence of communications and computing means that Moore’s Law is of increasing application to communication systems. The central planning model, based on a timing window of between 2 and 5 years is becoming less able to keep up with the roll-out of new communications/computing technology, which is taking place at roughly double that rate.

The Public Policy Review

Background to Reform

Electronic communication is fundamental to virtually every sector of a modern industrialised economy. The communications sector is one of the fastest growing sectors in the Australian economy (Australian Bureau of Statistics, 1997).

Acceptance of the importance of communications to economic activity has led to the radiofrequency spectrum being increasingly regarded as a national economic resource that needs to be managed efficiently for the greatest good of the nation.

Specific recognition of the economic value of spectrum came about against a background of micro-economic reform in the period from about 1987 to 1992. During that period, the telecommunications, radiocommunications and broadcasting regulatory regimes in Australia were all systematically reviewed as part of a wider government impetus for micro-economic reform.

The model of review and reform adopted by the Department of Transport and Communications (from which the ACA can trace its roots) included economic review of existing regulation by the Bureau of Transport and Communications Economics (BTCE) (Evans, 1992). In some cases, the review process also included a formal reference from the Government to the House of Representatives Standing Committee on Transport Communications and Infrastructure (HORSCOTCI) to conduct a Parliamentary Inquiry, as a way of exposing the policy issues to wider public scrutiny.

After the public review processes had identified the policy issues, the Government and its advisers set about developing public policy responses to the issues, and coordinating these responses across agencies. Once the Government had set the policy framework, it was translated into draft legislation for consideration by the Parliament. In the case of radiocommunications, this review process culminated with the passage of the *Radiocommunications Act 1992*.

BTCE Review

The BTCE’s Report into Radiocommunications (BTCE, 1990) was the first systematic review of the Australian approach to managing the radiofrequency spectrum resource to approach the issues from an economic perspective. After considering the existing planning, licensing, and fee setting activities, BTCE identified widespread inefficiency in many aspects of spectrum management in Australia, all of which flowed from the application of the central planning model.

These findings are summarised below.

The administrative system:

- *failed to accommodate changing demands and thus produce socially optimal outcomes.*

From the analysis of spectrum use undertaken by BTCE, it was evident that the supply of spectrum for specific uses, through the planning process, had not resulted in an even distribution of occupancy. Avoidable mismatches in supply and demand led to obvious efficiency losses. Not only could sections of the spectrum left lying idle be used to provide more services, but additional costs borne by users in congested bands could also be avoided by their relocation to less congested spectrum.

Mismatches of this kind occur because administrators are forced to anticipate technological and market developments in an environment of rapidly changing communications technology and user demand. No government agency can reliably predict public demand for specific services or the future direction of new technologies. Even if technology and the public's needs were unchanging, a central planner could only imprecisely evaluate the benefits of the myriad possible uses of spectrum and determine which frequencies should be used for each service.

- *provided limited mechanisms to potential users to obtain existing assignments*

Further inefficiencies in spectrum use resulted from assigning spectrum to users on a ‘first-come, first served’ basis, combined with virtual use in perpetuity. This meant that there were limited mechanisms for potential users to obtain existing assignments, other than to wait for frequencies to be relinquished or to purchase the company holding the licence. Such an approach tended to favour established applicants. If late-comers are more efficient but are unable to gain access or must accept lower quality access, the outcome is reduced economic efficiency.

- *provided no scope for individual users to negotiate among themselves to determine acceptable levels of interference*

BTCE pointed out that under the traditional administrative system, the maximum acceptable levels of interference for signals were preset by the central planners on technical grounds, usually to the point where interference was almost non-existent, with no allowance for the economic cost of this approach. Under such a system, there is limited opportunity for individual users to negotiate among themselves to share spectrum, to determine levels of interference they deem acceptable, or to choose the equipment which they deem appropriate.

- *had a pricing structure that failed to effectively control demand*

> Although some regard was given for setting the ‘price’ to balance supply and demand, the BTCE showed that such adjustments were not sufficient to achieve equilibrium. The BTCE noted that the current system fell short of the goal of rationing spectrum in the most economically efficient manner, largely because of inadequate flexibility to meet changing demand patterns. The BTCE also noted that the supply of spectrum to specific uses, as managed through the planning process, has not matched demand.

The BTCE’s proposed solution was to introduce a market-based model of spectrum management, and to substantially reform the administrative aspects of licensing, especially with regard to licence fees. BTCE argued that an economically efficient solution would be *to allow for a trade-off between the number of services and the quality of signals in accordance with changes in demand patterns, technology and methods of operating services* (BTCE, 1990, p.xviii). BTCE suggested that the market price mechanism would ration spectrum, and those who paid the highest price would be those who placed the highest value on the resource as an input to production.

In order for such a system to work, BTCE noted that it would be necessary to establish a legal framework which conferred *property rights* to spectrum access, regulated trading, facilitated the resolution of trading, and accommodated public and merit goods.

Since the early 1950s, the idea of property-like rights in radio spectrum has been popular with a wide range of economists and policy analysts (Hazlett, 1995). A number of definitions have been developed and proposed as a means of creating spectrum property rights. Essentially, they all rely upon defining spectrum access in four dimensions: time, geographic area [which is described in a two-dimensional plane] and spectrum channel. A user would have the right to transmit during particular hours of the day, over a specified geographic area, within a specified spectrum channel width, provided that the signals did not exceed certain levels outside the geographic area and spectrum channel. The user would be able to vary the uses and technical parameters within those rights. BTCE proposed a model which relied on the creation of “spectrum access rights” (SARs) which drew heavily on these fairly classical ideas. The BTCE saw a SAR being defined in terms of:

- permitted use;
- time of day of use;
- the frequency band authorised;
- the geographic area; and
- power levels at the spectrum and geographic boundaries.

The BTCE implementation of the model required the:

- creation of SARs with fixed non-renewable terms;

- conversion of existing assignments to SARs;

- open trading in, and leasing of, SARs;

- provision for amalgamation and subdivision of SARs;

- auctioning of SARs where appropriate;

- allocation of SARs over the counter in other cases at a price determined by efficient pricing principles; and

- cost recovery of direct charges.

Interestingly, BTCE seemed unwilling to question the central planning model's expectation that parts of the spectrum should be dedicated to particular uses, because it acknowledged that

> *SARs would be defined in terms of the* ***permitted uses****, the time of the day,* ***spectrum channel-width****, geographic area and the power levels at the spectrum and geographic boundaries* [my emphasis](BTCE, 1990, p.xix).

and

> *Through the market system, users and spectrum lessors would be encouraged to vary uses* ***(within prescribed uses)*** *to allow for increased participation of users in spectrum planning* [my emphasis] (BTCE, 1990, p.77)

The BTCE envisaged that the SAR holder could determine a particular use or uses (within the prescribed uses) and the number of services. A government regulatory agency would be responsible for determining interference levels and settling interference disputes, but under a less rigid approach than was being applied at the time. Single use SARs would be available where there were social or technical reasons to designate permissible uses.

Open trading and leasing of SARs would be permitted, but amalgamation and subdivision of SARs would require the approval of the regulatory agency. There would be a legal register of ownership similar to the registration of land titles. Sale prices would be recorded so that users, spectrum lessors, potential users and interested parties could monitor the market.

Where feasible, the BTCE recommended that auctioning be used to sell any unused spectrum. Newcomers wishing to acquire SARs in congested areas, whether for an existing use or a new use, would need to purchase them from existing users. Where auctioning was not possible, SARs would be sold over-the-counter at a price equal to the administrative cost of issuing the SARs. An annual charge would be applied to all SAR holders to cover the costs to the regulatory agency, and not recouped through other more direct means.

The BTCE suggested that this framework would create an environment that would maximise the net returns realised from spectrum access. A market in spectrum access through SARs, together with auctioning and an appropriate pricing system, would ensure that spectrum would be considered an asset from which users would attempt to maximise their return. The users who expect to obtain the highest net returns would gain access and they would have incentives to manage their SARs to produce these benefits. This would be a dynamic process, as the net benefits from different uses, equipment and practices changed over time.

BTCE proposed that SAR holders would have the legal right to transmit and to be free from interference within these boundaries. The advantage of such a system would be that it would allow spectrum users much greater autonomy over the design and siting of devices, effectively taking over the licence assignment role traditionally undertaken by government. In this model, government would still be responsible for international coordination, national spectrum planning, and, to the extent that use was necessary for particular bands, the government would also be responsible for band planning. The primary efficiency gain in the BTCE model resulted from the use of market mechanisms as a licence allocation tool.

SARs could be traded in the BTCE model, but BTCE envisaged what we regard today as a very limited form of trading:

> *Buying, selling and subleasing of all SARs (radiocommunications and broadcasting) would be through an open market system. If the SARs were sold, the new holder would be restricted to the condition relating to prescribed uses, the time, spectrum and geographic dimensions and the interference parameters. ....However, if holders wished to amalgamate or divide SARs in time, spectrum or geographic dimensions for separate sale, approval would be required, as this would change the interference parameters.* (BTCE, 1990, p.83)

This last sentence brings out what, with hindsight, seems to be the biggest limitation in the BTCE's approach - that the interference management framework would always be dictated by the hierarchy of planning instruments, and that trading of spectrum as a resource would have to be constrained by determining spectrum "use".

BTCE worked through the application of SARs at an economic level and described how SARs would permit the management of spectrum by private companies, effectively breaking the government monopoly on every level of management. BTCE's model suggested that in congested areas, blocks of spectrum could be sold as SARs to new owners who could lease access to that space to other users, effectively in direct competition with the central government agency.

BTCE acknowledged a number of criticisms of the model, but essentially these criticisms were from the point of view of economic theory, and BTCE was able to address them. At no stage, however, did the BTCE actually consider the practical implementation of such a model. It is worth noting that while BTCE acknowledged that the classic property rights model had existed in the literature for some time, at the time of the BTCE paper, no one, other than the New Zealand Government, had attempted to implement such a thing.

HORSCOTCI Report

On 23 July 1990, the Minister for Transport and Communications at that time, Hon. Kim Beazley MP, requested the House of Representative Standing Committee on Transport, Communications and Infrastructure (HORSCOTCI) to hold a public inquiry into the efficiency and effectiveness of spectrum management arrangements in Australia. The BTCE economic review formed an important reference document to the inquiry.

The Committee tabled its report entitled, *Management of the Radio Frequency Spectrum* in Parliament on 17 October 1991. The Committee considered evidence in over seventy written submissions and at six public hearings, representing the views of commercial and non-commercial spectrum users and industry associations.

HORSCOTCI's main conclusion was that the existing administrative system of spectrum management would not provide an efficient or effective means of addressing Australia's long-term spectrum requirements.

The Committee recommended the introduction of a mixed administrative/ market-based system of spectrum management involving the gradual commencement of trade in spectrum resource and the fine-tuning of the current administrative system.

In general, HORSCOTCI agreed with the conclusions of the BTCE regarding inefficiencies in the management of spectrum. It highlighted these as:

- dynamic efficiency - highlighting that current practices lack flexibility and timeliness with regard to changing demand for spectrum;

- technical inefficiency - concluding that the Department of Transport and Communications was constrained in its ability to ensure that the most efficient equipment and practices are in use;

- efficient provision for public and merit goods - highlighting the need for efficient use of spectrum, particularly with respect to public sector uses;

- allocation of spectrum to the highest valued use - noting that the current system could not do this, and that this would become a critical issue if demand continued to increase and congestion became more commonplace.

HORSCOTCI also concluded that the current approach to levying charges had little effect in managing demand, did not promote efficiency, and was not transparent to users.

HORSCOTCI, however, was more reserved about the application of a full market model, arguing that such a model raised some particular concerns in public policy. Instead, HORSCOTCI proposed a mixed market/administrative approach to spectrum management. The concerns identified by HORSCOTCI which prompted this approach included:

. uncertainty about interference management;

. concern about access for non-commercial users of the spectrum;

. concern that long term planning might be compromised if spectrum were to be "sold-off";

. and concern about "market dominance" and the possibility that a market system might be subverted to anti-competitive effect (HORSCOTCI, pp.94-99).

The Government tabled in Parliament an interim response to the HORSCOTCI report in December 1991, followed by a full response in September 1992. The Government adopted many of the HORSCOTCI recommendations as a basis for spectrum management reform, including the core recommendation of a mixed market/administrative approach.

In line with the HORSCOTCI recommendations, the Government adopted a spectrum management reform strategy involving:

. the selective and progressive introduction of a market-based system of spectrum management to operate in defined spectrum segments alongside the administrative system;

. improvements to the efficiency and effectiveness of the administrative system; and

. the establishment of the Spectrum Management Agency (SMA).

These reforms were enacted by the Parliament in the *Radiocommunications Act 1992*.

Implementing Spectrum Property Rights

At the time the SMA was created in July 1993, the law provided for ***spectrum licences***, as a form of property-like right. At the time, however, the Agency had little idea about how to implement such a thing. There was theory, and there was law, but there was no practice. The SMA's own engineering and technical staff saw major difficulties standing in the way of implementation.

The Spectrum Marketing Team (SMT) was created as a multi-disciplinary team, tasked to implement spectrum licensing and implement the law.[1] SMT produced a number of discussion papers that explored the issues in setting an engineering framework for spectrum licensing to manage interference. These papers were accompanied by a series of case studies developed to explore how these concepts might work in an operational setting. It is fair to say that the papers and the concepts embodied in them were politely considered within industry, but were generally treated with suspicion. It seemed to many that spectrum licensing was incapable of being implemented, and indeed the view of some in the radiocommunications industry was that it should not be implemented.

Notwithstanding the critics, the goal of SMT has been to implement, within the law, a tradeable, technology neutral spectrum access right that allows market mechanisms to not only allocate the spectrum resource between users, but also to allow those users to select their own technology.

The Problem

To many people in the newly created SMA, the ideal of a spectrum property-like right which placed planning and licensing in the hands of the "market" (with its perceived attendant evils) seemed fundamentally dis-empowering. Many staff believed that the concepts articulated by the economists could *not* be implemented, because these concepts ignored the physical properties of radiofrequency radiation. Suspicion of spectrum licensing was not helped by the limitations of the model proposed by BTCE in dealing with practical radiocommunications. That model seemed to fit uncomfortably with the laws of physics. There seemed to be no acknowledgment in the model of the mechanisms needed to properly manage interference, and so maximise spectrum utility. Indeed, it is my view that the classical spectrum property model, articulated by the BTCE and implemented literally in *the Radiocommunications Act 1992*, is in many ways incomplete. The implementation of true spectrum property-like rights requires a number of additional and far more complicated mechanisms than provided in the BTCE's SAR model.

Concerns about the BTCE SAR Model

By creating rights in area, time and frequency bandwidth, the SAR model requires the creation of exclusive rights in a four dimensional continuum (time, frequency and two dimensions describing area)[2]. The task for the regulator centres around developing a licence system (and therefore a recording system) that is capable of recording and maintaining exclusive access in these four dimensions. This is no trivial matter.

The model also relies on imposing "limits of power levels at the geographic and frequency boundaries", which poses a significant problem for the regulator! In the event of a complaint, the regulator has to establish ***as a matter of fact*** whether or not the

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1 I was recruited to lead SMT in October 1994

2 While the spectrum space is four dimensional, the SMA found it convenient to ignore the time dimension as an aid to understanding. Three-dimensional space is mush easier to conceptualise than four-dimensional space.

power level has been breached. As our engineering and field technical officers were quick to point out, many phenomena in radiofrequency propagation lead to situations where power levels ***cannot be measured accurately***. Indeed, there are situations where power levels measured only metres apart may be substantially different! The idea of absolute and measurable power levels at boundaries is unworkable. Many other technical considerations that directly affect the utility of spectrum and the management of interference are ignored in the BTCE model, including issues associated with co-siting devices, management of inter-modulation products, deployment constraints for duplex operations, and so on.

The SMA's challenge was to develop an engineering framework to support our objective for spectrum property-like rights that deals with all of these issues, within the framework provided by the law. These issues were solved by the SMA and the mechanisms published (SMA, 1996). The detailed engineering behind them is beyond the scope of this paper, but it relies essentially on a sophisticated terrain model[3] and geographic information system (GIS) capabilities to make reasonably accurate predictions of propagation loss. These predictions are used to establish a theoretical *device boundary* for a proposed device (Whittaker and Yang, 1997). Provided that the device boundary of a proposed device falls wholly within the geographic and frequency bandwidth boundaries of the licence, then the device is deemed not to cause unacceptable interference. This gets the regulator out of the difficult issue of having to measure power levels at boundaries. Even using these sophisticated models and techniques, it is not possible to totally remove the incidence of interference. Indeed, the model actually *requires* a small probability (about 1 per cent) of actual interference occurring in the field, because this provides some feedback about the level of spectrum efficiency within a band. Too little actual interference being reported, and the spectrum utilisation authorised by the technical framework might be too low. Too high a level of actual interference would indicate too liberal a regime.

Turning the Dream to Reality

While most of the attention of industry concerned the development of an engineering framework for managing interference that fitted the laws of physics, the central issue of how to manage a property-like right with enforceable boundaries in something as abstract as radiofrequency spectrum remained unaddressed.

The first hint of recognition that a solution might be at hand came in March 1995, when the SMA released its public discussion paper *Implementing Spectrum Licensing.* In that paper, while addressing the issue of how spectrum might be marketed (ie. how parcels of spectrum space might be defined and allocated), the SMA suggested three approaches:

- an approach which authorised use of spectrum to the full limit of the designated band, over all of Australia;

[3] This digital elevation model, called RadDEM, has a resolution over all of Australia of 9 seconds of arc (about 250m, depending on latitude). RadDEM has been published on CD-ROM and is available for purchase from the ACA.

- a service-related approach which sub-divided a band into packages that were designed to cater to certain services types and/or communities of interest (not unlike existing practice in the broadcasting sector); and

- a modular approach, which sub-divided the band into standard blocks which could be aggregated in response to market conditions to cater to individual licensee preferences (SMA, 1995, pp.24-26).

To promote flexibility, and so deal with the deficiencies identified by BTCE and HORSCOTCI regarding the lack of flexibility in the existing system, the SMA openly favoured the modular approach. The feeling was that this might open the way for the market to influence decisions about spectrum use, taking reform much further than BTCE contemplated, and into the spectrum plan/band plan area.

The modular approach sees spectrum being sub-divided in area and bandwidth into small and arbitrary commodity units of spectrum space. Utility comes not so much from the blocks themselves, but from the ability to aggregate the blocks, either in coverage area, or in bandwidth to provide increased coverage, or increased bandwidth, or both.

In early thinking, the SMA conceived these blocks being hexagonal in area, following standard engineering practice that planned for spectrum re-use on a hexagonal cell structure. Hexagons are able to be configured in a regular repeating lattice (like a honeycomb) and loosely approximate a circle, so mimicking the popular analogy for radio waves as being like the ripples created on a pond by a tossed pebble.

On evaluation, however, it became clear that the mythical circular propagation plot hardly ever occurred in nature, mainly because of the effects of uneven terrain loss. It was therefore not necessary for the SMA to use hexagons as an approximation to circles, for circles didn't occur anyway. The SMA settled on using squares bounded by parallels of latitude and meridians of longitude. The areas thus created are literally *curvilinear trapezoids*, but can be represented through map projection as squares. The regularity of these curvilinear trapezoids, and their definition in terms of the national spheroid, made mapping and projection a simple matter.

In the frequency dimension, the SMA conceived that a band would be subdivided into blocks of a standard bandwidth. The optimal size of these blocks would be determined by the SMA to satisfy two goals:

- firstly, to enable efficient use by the most narrowband service thought to want to operate in the band; and

- secondly, to provide a size that provided the lowest common denominator of bandwidth for the variety of possible communication systems in the band.

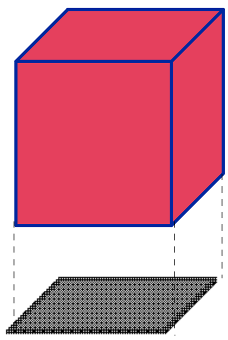
In order to exploit the flexibility that this model provided, the SMA's engineering framework was developed to manage interference at the boundary of these basic units of spectrum space, rather than being developed to reflect a particular use or service as the BTCE model proposed. The advantage of the SMA approach is that it allows the aggregation of spectrum space without affecting the boundary conditions that apply – these remain constant, no matter what technology or system is deployed. In order to accommodate a system that requires a large amount of spectrum space, the engineering framework requires the operator to buy a lot of spectrum space so that the device emissions can always be managed within the standard framework.

The impetus for these ideas came from an operational imperative: *to design a computer database in which to record ownership of spectrum space*. One of the requirements of spectrum licensing is exclusivity of "ownership", and the challenge was to develop a database structure that allowed conflicts in exclusivity to be identified algorithmically in all four dimensions of the spectrum continuum. The simplest solution was to establish a commodity unit, to which all trading and access would relate. For each commodity unit, there could be only one logical owner.

The commodity unit of spectrum space, when first described, was called a "smallest trading unit", because that was what it was - the lowest common denominator building block of spectrum space. This subsequently changed over time to "standard trading unit" or STU for short. STUs are the basic building blocks from which usable spectrum space can be built. By definition, the SMA made STUs finite, indivisible and able to be combined with their neighbours into large spectrum spaces with more utility. Conversely, large spectrum spaces can be disaggregated in the market place in terms of STUs, allowing for the first time commodity trading in spectrum space.

STUs are four-dimensional units of spectrum space. They occupy an area (two dimensions), they have a bandwidth (or frequency range) and they exist in the temporal dimension. To aid understanding, however, the SMA conceived of STUs as cubes (Figure 1.), with area coverage on the horizontal plane and frequency bandwidth on the vertical axis. Time is generally ignored to aid practical understanding of how spectrum space can be manipulated. A single STU is the smallest unit of spectrum space for which the ACA will issue a licence or register trading.

Figure 1 - Standard Trading Units.



Standard Trading Units are like cubes of spectrum space

In the area dimension, the SMA created a "spectrum map grid". This is a grid of parallels of latitude and meridians of longitude that defines 21,998 cells. These cells exist in three separate sizes, depending on population density:

. 3 degrees of arc in remote areas;

. 1 degree of arc in rural areas; and

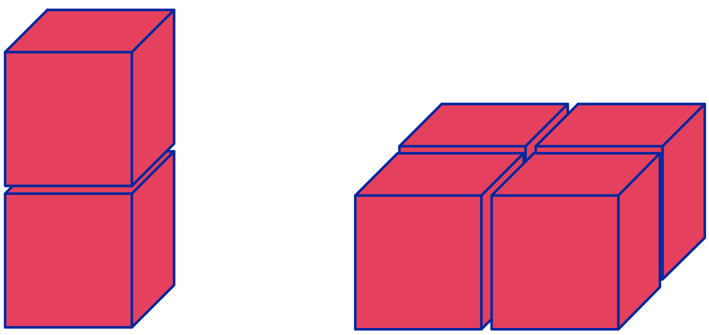
. 5 minutes of arc in metropolitan and regional areas.

The area of every spectrum licence must be defined in terms of these cells.

Each spectrum licence is an aggregation of a number of STUs that have been combined like building blocks to form usable spectrum space. Licensees have the flexibility to aggregate spectrum access in the marketplace to cover additional areas, or a wider frequency bandwidth (Figure 2.), without having to return to the ACA for additional spectrum licences. Alternatively, licensees can sub-divide their spectrum access into a number of narrower bandwidth channels, or a number of smaller areas within the main area or both. This mechanism, more than any other, facilitates market-based responses to the emergence of new technology. A licensee wanting to introduce a new technology can enter the market place and buy the spectrum space it needs directly, without having to wait for the planning cycle to make provision for that technology.

It is important to remember that spectrum licensing does not exist in isolation. There is still a need to register devices that are deployed in the field, for each new device contributes to the overall radio environment, and this environment still needs to be managed. There is still a need to ensure that devices, when they are operated, will not create unacceptable interference to devices operating in neighbouring properties.

Figure 2. Aggregation of Standard Trading Units



STUs can be stacked vertically (left) to provide increased bandwidth, or horizontally (right) to cover a larger area

While it is true that licensees are free to deploy any technology, any device, from any site in their licence, it remains the licensee's responsibility to ensure that the device will not cause unacceptable interference. Under spectrum licensing as implemented by the SMA, each licensee has the flexibility to change equipment, antennae, siting, or any other aspect of its use of spectrum, provided they comply with the technical conditions of the licence and the engineering framework.

Allocating Spectrum Licences

With the theory behind a tradeable and technology transparent spectrum access right comfortably settled, there remained the significant problem of allocating these rights in a way that did not compromise the objectives of reform. SMT wanted to exploit the benefits of the modular approach and allow market conditions to determine how arbitrary blocks of spectrum space would be aggregated into the preferred configurations of the market place.

Price-based Allocation

The *Radiocommunications Act 1992* required that spectrum licences be allocated by using a price-based system. The Act defined this as an auction, tender or predetermined or negotiated price. The clear intention was that market conditions should prevail in allocating these licences, rather than administrative pricing, comparative merit assessment, lottery or ballot.

Australian Experience with PBAs

In 1993, Australia adopted price based allocation methods for issuing Pay TV licences. The tendering procedures involved the submission of written bids in sealed envelopes, payment of a non-refundable application fee of $500, and a statement of the applicant's industry plan, and the proposed ownership and control structure of the applicant's operating company.

There was a significant flaw in the rules that underpinned the tendering process. Bidders were not explicitly prohibited from submitting multiple bids for the same licence, nor were they compelled in any way to meet their financial commitments. Licence bidders were able to engage in a strategy of submitting 'cascading' bids; ie. a series of bids in descending order of magnitude. This meant that the eventual winner did not pay their highest bid price but some lower amount drawn from their cascading menu of bids. This process resulted in some embarrassment for the Government, and highlighted the importance of careful auction design (Cheah, 1994, pp.21-25).

On the creation of the SMA in July 1993, the Agency inherited a requirement to allocate MDS licences that had been subject to an aborted tender the previous year. The SMA chose to allocate these licences using a conventional English (open oral outcry) auction. Despite adopting a conventional auction design, the SMA carefully developed a set of rules aimed at preventing a repeat of the previous experiences. In 1994 and 1995, the SMA successfully concluded auctions for apparatus licences in the MDS bands and generated A$100.2m from the sales.

While the English auction approach is undoubtedly capable of allocating individual apparatus licences, it suffers an obvious and fatal defect in any situation where an applicant is seeking complementary licences, or in the case of spectrum licensing, complementary components of a licence. In the case of spectrum licensing, it cannot meet the expectation to allow market conditions to guide efficient and optimal organisation of spectrum lots into preferred aggregations. This is because an English auction design allocates lots sequentially. Bidders do not know whether they will be successful in obtaining the other components of their preferred aggregation. This weakness was also noted by the SMA for "Dutch" (descending bid) and "Vickrey" (second price) auctions and sealed bid tenders. Each of these designs would have required the SMA to offer properties that reflected the SMA's own assessment of the likely use, and thus would have pre-judged the market.

The *simultaneous ascending auction* system[4] developed for the US Federal Communications Commission (FCC) to allocate radiocommunications licences for personal communications services (PCS), seemed not to suffer from this weakness. By offering all lots in parallel over multiple rounds, this design seemed to actively encourage the emergence of market preferred aggregations. It allowed bidders to bid on their preferred aggregations, without the risk of being unable to secure all of the elements of their preferred aggregation.

Design Challenges in the Australian Setting

The US PCS spectrum auctions were essentially two-dimensional auctions, in that aggregation of licences was only possible in the horizontal plane - that is, area coverage. The US auctions did not really contemplate or permit (through ownership and control limitations) the vertical aggregation of spectrum space to increase bandwidth. The US auctions were for “licences” following the traditional centrally planned apparatus licence approach.

In the SMA model, however, the goal was to use the auction mechanism to facilitate preferred aggregations in ***all three*** dimensions of area coverage and bandwidth.

In implementing this auction design, the fundamental issues for the SMA were:

- development of auction rules that were capable of sustaining a three dimensional auction;
- implementation of an auction management system; and
- selection of optimal market design in terms of the number of lots, and the shape of the lots.

The first spectrum licence auction was scheduled to take place in the 500 MHz bands, in spectrum that had been cleared in the later 1980s and then left unused. This band was selected as an ideal low-risk proving ground for the SMA’s “radical” new ideas.

Auction Rules

The challenge with auction rules was to take the basic US design and translate it into Australian “legalese”, consistent with the *Radiocommunications Act 1992*, and the wider Australian legal framework. To do this, the SMA contracted a retired head of the Office of Legislative Drafting (OLD) to work directly with SMT to craft the rules. Despite having this very experienced legal drafter, the translation of the auction design took nearly 8 months.

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[4] For detail about the development of the simultaneous ascending auction design and the theory underpinning it, see Milgrom (1987,1989), McMillan and McAfee (1987, 1996) and Wilson (1992)

Since the auction design was new to Australia, and the SMA was keen to avoid unnecessary risk, it commissioned Charles River Associates (CRA) in association with Market Design Incorporated (MDI) to review our rules. The brief to CRA/MDI asked for a review of the translation of the auction rules, some assessment of the SMA's market design proposals, advice about possible improvements, and certification that the rules implemented a robust auction methodology. MDI has, as principals, noted auction design authorities such as Professor Paul Milgrom, Professor Bob Wilson, Professor John McMillan, Professor Preston McAfee and Professor Peter Cramton, all of whom were involved as advisers during the FCC auctions. Charles River Associates brought to the partnership Dr David Salant who also advised during the FCC auctions.

Following a detailed and generally favourable report from CRA/MDI, the SMA had a high degree of confidence in its auction design, provided that some minor modifications were implemented.

Having auction rules was one thing - being able to conduct an auction was another entirely.

Auction System

In late 1995, I travelled to the US to attend a conference at Princeton University, which reviewed the FCC's experience with this form of auction. Part of that mission included meetings with FCC officials in Washington DC to explore implementation of an auction system, including gaining an understanding of the computing infrastructure necessary to support an auction, and to source computer software.

Discussions to purchase software from the FCC never progressed beyond polite informal exchanges because the price tag that the FCC had put on its software, initially suggested to be around US$400,000, was considered to be far too high by a factor of about 10.

The SMA decided early in 1996 to develop its own software, using rapid application development (RAD) techniques. A budget of around $50,000 was felt to be feasible for all systems development, and provision was also made for fitting out a secure auction facility, and fitting the facility out with the necessary computer infrastructure.

The total cost to the SMA for all of this activity was less than $140,000, and well within the overall budget provision for the development and implementation of the spectrum licence concept. It is interesting to note that this cost was fully recovered in the first ***15 minutes*** of bidding in the 500 MHz auction, and was a fraction of the price originally suggested by the FCC for their software alone.

The SMA's software implemented a number of design enhancements compared with the FCC system, including map-based point-and-click functions to select areas for bidding, and a number of error detection and warning routines.

Prior to deploying the auction system, Deloitte Touche Tohmatsu audited it end-to-end (twice). The SMA had a good deal of confidence in the system. In addition to the audits, the SMA conducted a live "trial" auction that ran for 15 rounds. The participants in the trial included all bidders registered in the 500 MHz auction, plus an additional 15 industry, government and individual bidders who volunteered to assist in testing.

Market Design

The last significant issue in the implementation of simultaneous ascending auctions for spectrum licences concerned the lots that should be offered for allocation. The issues were, for a three dimensional auction, how many areas and how many bandwidth divisions should be offered.

This points to a very real and practical dichotomy in auction design. On the one hand, theory would suggest that ultimate flexibility comes from offering a very large number of small and arbitrary allocation lots. Large numbers of small lots permits a wider set of permutations of bidder preferences to be satisfied, and so should yield a more efficient outcome. On the other hand, large numbers of lots present an administrative problem for bidders that even the most sophisticated information systems support is unable to address. In theory at least, the SMA could have offered 21,998 STU area grid cells, multiplied by 8,000 1 kHz bandwidth divisions: more than 175 million lots. The information systems necessary to allow bidders to bid on this number of lots from their own desktop would have been formidable. The problem for bidders in tracking 175 million lots also defies contemplation. At the other end of the scale, the SMA could have conducted an "English" auction, for one lot, covering the whole bandwidth, over all of Australia. The problem for bidders would be reduced, but that would not necessarily result in an efficient allocation. There could be only one "winner".

In all of the SMA's development of spectrum licensing, staying true to the theoretical ideal, while important as a goal, has always been tempered by pragmatism in implementation.

In early thinking, the SMA considered a large number of arbitrary areas, possibly as many as 50, and up to 50 bands, giving potentially 2,500 allocation lots. Advice from Professor John McMillan during a visit to the SMA, however, suggested that this might be too ambitious. No one had attempted to run an auction of this size. On the basis of Professor McMillan's advice, the SMA's proposals evolved into the final market design offered in the 500 MHz band auction: 17 areas and 54 bands. When some combinations of area and band were withdrawn from sale for technical reasons, the SMA was left with 838 allocation lots.

Each lot on offer was a collection of STUs. In the area dimension, 17 areas were created from the spectrum map grid of STU cells. The areas were defined by considering a population density model, the digital elevation model (RadDEM), existing radio sites, and propagation models of typical transmitters operating from those sites. In other words, the SMA accepted the pragmatic need to undertake some judgement about practical market design, basing areas on real markets and practical spectrum use.

The SMA defined for the 500 MHz auction an STU bandwidth of 12.5kHz . In the 4

MHz paired configuration (a total of 8 MHz) on offer in the 500 MHz auction, this provided for 640 separate STU bandwidths. The SMA aggregated these to assemble the 54 bandwidth parcels offered for sale. To promote both large and small users getting access to spectrum, lot bandwidths varied from 12.5 kHz (1 STU), 25kHz (2 adjacent STUs), 100 kHz (8 adjacent STUs), 500 MHz (40 adjacent STUs) and 1 MHz (80 adjacent STUs). Again, this reflected a degree of pragmatism. The prospect of offering bands at the STU resolution simply resulted in too many lots for practical management or understanding from our bidders.

500 MHz Band Spectrum Licence Auction

The 500 MHz band spectrum licence auction took place between 3 February and 25 March 1997. It concluded after 64 rounds and raised A$1,062,077.32, including bid withdrawal penalties. There were 13 registered participants in the auction and all but one were successful in winning lots in one or more areas. The SMA issued 10 year non-renewable licences with effect from 1 June 1997. The highest bid of A$53,335.50 was made on a 1 MHz lot in Adelaide. On a population basis the highest bids were received in the Townsville area. Nelson (1997) provides a fuller analysis of the results of the 500 MHz auction.

In terms of the goals of spectrum licensing, the simultaneous ascending auction design has enabled the successful implementation of a technology transparent spectrum access right.

A notable feature of the results of the auction is the wide variety of different bandwidth configurations that were won by the successful applicants. It suggests strongly that the theoretical prediction that this form of auction facilitates efficient aggregation of lots to satisfy market preferences has been satisfied.

Feedback from the successful applicants indicates that potential service configurations are as varied as trunked mobile voice and data communications, fixed wireless modems for data and protection of wideband telecommunications systems. This variety could not be contemplated easily under the centrally planned approach to spectrum management. The ACA now understands that some of the successful applicants purchased spectrum for investment purposes, or to establish licensing schemes in competition with the ACA's own licensing activities; again, consistent with the goals of reform.

A number of lots did not attract bids and were passed in at the auction. The ACA is considering, in the light of post-auction queries, to conduct another smaller auction later this year to dispose of the unsold lots. Several licensees have also indicated that they regret not making larger "eligibility payments"' that would have allowed them to acquire more spectrum in the 500 MHz auction.

The auction has demonstrated that market mechanisms can be used successfully to allocate spectrum for competing uses and technologies. The success of the auction gave the SMA the confidence to recommend that spectrum licensing and spectrum auctions be the preferred mechanisms for allocating spectrum for new telecommunications services later this year.

The Future of Spectrum Licensing in Australia

In order to meet the Government's objectives for a more open and competitive telecommunications market after 1 July 1997, the ACA will re-allocate parts of the 1.8 GHz band and parts of the 800 MHz band by issuing spectrum licences. This spectrum is to be auctioned using the simultaneous multiple round auction system in late 1997/early 1998. This will provide additional capacity for new services, including new personal communications services (PCS), which in turn will lead to increased competition in the provision of mobile telephony.

The ACA considers that making a considerable amount of spectrum available in both the 1.8 GHz and 800 MHz bands will provide good opportunities for new telecommunications services to emerge, for existing carriers to expand, and for a range of technologies to be deployed.

On 15 July 1997, the ACA released its draft plans for the spectrum auction, including details of the lots to be offered, their bandwidth and area coverage. Twenty one areas and 22 bandwidth parcels were outlined in that documentation and were subject to public comment. For a number of reasons, not every combination of area and bands permitted, and so the total number of allocation lots 230. This is an even simpler market design than that attempted in the 500 MHz auction.

Comments on these proposals closed on 12 August 1997, but on 24 September 1997, the Minister for Communications and the Arts, Senator the Hon Richard Alston, announced that he had asked the ACA to defer the auction of this spectrum until 1998 to allow the Government to ensure that the regulatory environment encourages the entry of efficient new carriers (Alston, 1997).

The auction of 800 MHz/1.8GHz is expected to generate wide industry interest. The spectrum auctions in the United States have been very successful in allocating licences efficiently, and have attracted interest from around the world. Allocation of this spectrum is expected to usher in new players leading to increased competition, which should increase service innovation and decrease prices.

In the first half of 1998, the ACA plans to allocate spectrum in the 28 GHz area, again using the simultaneous ascending auction system to allocate spectrum licences. One of the issues for the ACA's 1997/98 work program is to develop a forward work program for future spectrum allocations, with SMT's goal being to increase through-put capacity to at least 6 auctions per year.

Conclusion

Radiofrequency spectrum is an important national economic resource, which forms an input cost to virtually every sector of the Australian economy. It is important to our national well-being that this resource is used efficiently and effectively. Increasing demand for spectrum services, congestion in and competition for prime blocks of spectrum, the rapid pace of technological change and service innovation, and recent structural reforms in telecommunications, have placed the traditional administrative system of spectrum management under increasing pressure. To meet these challenges the SMA implemented significant reforms in spectrum management. A major part of these reforms has been the selective introduction of a market system of spectrum management of which spectrum licensing is an integral component. The SMA successfully deployed the US designed simultaneous ascending auction to allocate spectrum licences.

This auction design, unlike many others, allows market factors to determine the allocation of spectrum resources between users, and also allows preferred aggregations of spectrum to emerge in response to market conditions. This provides for market conditions to be a determinant of spectrum use.

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