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Benoit P. Freyens
University of Wollongong, bfreyens@uow.edu.au

Mark Loney
ACMA

Michael Poole
ACMA

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Wireless Regulations and Dynamic Spectrum Access in Australia

B. P. Freyens[†], M. Loney[‡] & M. Poole[‡]
[†] University of Wollongong
NSW 2500, Wollongong, AUSTRALIA
[‡]Australian Communications and Media Authority
PO Box 78, Belconnen ACT 2616
Canberra, AUSTRALIA

Abstract[1] - Australia assigns and allocates spectrum using three broad types of regulatory approaches; command and control, property rights and open access. Each approach entails numerous pros and cons, buttressed by uncertainties over future consumer demand, interference management, barriers to entry, and technological evolution. The development and commercialisation of dynamic spectrum access technologies (DSA) requires new regulatory approaches. This article discusses an array of intermediary, dynamically efficient spectrum management approaches, which may make better use of DSA opportunities. The article then discusses the practical hurdles and legal challenges posed by their adoption and regulation in an Australian context.

INTRODUCTION

Since the early 1990s, various OECD countries have assigned and allocated the radio spectrum to specific users and services using three broad regulatory regimes; command and control (C&C), property rights and open access. Command and control is a managed licensing regime in which the degree of user discretion with regard to service and technology neutrality is either nonexistent or minimal. The property rights regime is an exclusive licensing regime in which ‘owners’ have significant discretion (‘rights’) in the selection of the technologies and services to be deployed in their licence area. Property rights also encourage the creation of secondary markets in which spectrum can be traded or leased. The open access approach is an unlicensed or non-exclusive licensed regime in which every user has identical usage rights provided they adhere to a specific set of rules and equipment standards.

Analysts’ views and recommendations on these regulatory approaches differ widely. Over the years, an ‘either or’ debate raised by various reformist factions has raised a large number of relevant concerns. There is now a significant and vigorous literature debating the benefits and drawbacks of these three regulatory regimes.

In our view this reform debate has erred, fixated on the need to promote either property rights and markets or open access regimes. Arguments have stressed the mutually exclusive nature of these regimes [1-5]. However, this polarisation of opinions is an unnecessary distraction. Property rights and unlicensed approaches mostly compete for different markets, services and devices, and should in fact better be viewed as complementary rather than rival approaches.

A consensual view, perhaps, is that the selection of a regulatory regime should be carefully adapted to the circumstances of the services considered (e.g. underlying context and market, public or private good nature of the service, technologies used, strategic importance of innovation policy, etc.).

Beyond the ideological nature of the debate, these regulatory approaches are also part of a wider dilemma over how to appropriate and distribute the rents generated by exclusive or semi-exclusive wireless access rights [6, 7, 5, 8]. The property rights regime has been particularly polemical among academic and policy researchers[2]. Although it has proved very successful among spectrum privatising countries[3], numerous commentators have stressed the potential for ‘hold ups’ which generate idle or underused private spectrum legally inaccessible to other potential users. This view of

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[1] Contacts: Benoît Pierre Freyens, Lecturer, School of Economics, University of Wollongong, NSW 2500, Australia, and Visiting Fellow, Australian National University, Tel. +61-242214399, Fax: +61-242213725. Email: bfreyens@uow.edu.au and ben.freyens@anu.edu.au. The views presented in this paper are our own and are expressed as private individuals. These views should not be assumed to represent the views of our respective institutions.

[2] The most recent contributions to this ‘either or’ debate include Refs. [9-15, 4, 16-18]

[3] These countries consist of Australia, Canada, El Salvador, Guatemala, New Zealand, the USA and, very recently, the United Kingdom. Except for Guatemala, which enshrined property rights in legal deeds, property rights in these countries are usually implicitly rather than explicitly defined.

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private spectrum as fenced oligopolistic enclaves is not shared by all. For instance, Hazlett [5] recently suggested that nonspecific expansion of property rights may increase competitiveness in wireless markets - as opposed to the static quasi-monopolies granted through command and control. While this argument is empirically tested and appears valid, in practice it ignores that property rights regimes also generally provide more entrenched legal rights (such as the rights not to tolerate secondary access or the right to be compensated for relocation costs) than command and control regimes (since the government can always modulate by decree the desired degree of exclusivity). More entrenched access rights for some users may well reduce opportunities to fully and dynamically exploit idle spectrum for other users.

Recent advances in the development and commercialisation of dynamic spectrum access technologies (DSA) require the regulatory framework to adapt flexibly to opportunities for greater spectrum utilisation. With DSA wireless networks, secondary users can access idle spectrum opportunities dynamically to transmit their signals whenever primary users do not use their licensed spectrum. .Much of the discussion has so far focused on uncertainties surrounding the commercial deployment of DSA technologies. There has also been much debate as to whether these technologies would favour a licensed or an 'unlicensed' approach to spectrum management. Although this question has been answered many times [19, 13, 16], it is essentially the wrong question [20].

This article takes a step back from the 'either or' dichotomy, which characterises much of this literature. It examines instead an array of intermediary—rather than extreme—spectrum management approaches that would be required to unleash the full potential of commercially deployable DSA technologies. The article argues that spectrum efficiency would be improved through the implementation of these intermediary approaches. Furthermore, we discuss the practical hurdles and legal challenges posed by the adoption and regulation of DSA technologies in order to enable new spectrum management regimes in an Australian context.

The article is structured as follows: the first section presents the 'trichotomic' set of radiocommunications systems in Australia and the spectrum management regimes they enable. The second section succinctly presents a taxonomy of spectrum management regimes. The third section presents a set of dynamically efficient intermediary regimes under this taxonomy and records attempts to implement some of these regimes in Australia. The fourth section discusses which of these intermediary regimes would best enable the opportunities presented by DSA technologies. The fifth section discusses the state of adoption of DSA technology in Australia and the regulatory hurdles in adopting or experimenting with DSA-efficient regimes in Australia.

Licensing spectrum rights in Australia

Spectrum policy reforms started in the late 1980s in Australia, culminating in the *Radiocommunications Act 1992* (the Act) and the first auction of spectrum licences in 1997[4]. The Act defines the operations of three radiocommunications licensing regimes; apparatus, spectrum and class licences, which map (imperfectly) with command and control, property rights and open access approaches, respectively.

Apparatus licensing is a device-centric approach, where the operation of every radiocommunications device is authorised through a transmitter or receiver licence. Most of the time, this device-centric regime is highly prescriptive, specifying the type of service, technology and equipment standards, along with tight technical conditions about site, band, power, and emission types. The Australian Communications and Media Authority (ACMA) has specified different types of apparatus licence that generally align with service designations in the ITU Radio Regulations.

However, not all apparatus licences fit the stereotype of an arch-rigid management regime ruled by government-fiat. For example, the 1993 launch of second generation (2G) GSM digital mobile telephone services in Australia was enabled by technologically flexible (but service-specific) apparatus licences for frequencies in the 900 MHz band. These licences allowed the use of any technology to provide digital mobile telephone services and today both 2G (GSM) and 3G (WCDMA) technologies are deployed in the 900 MHz band. Also, the Act was amended in 1995 to allow the trading of apparatus licences and third party operations (e.g. leasing), which introduced a degree of market flexibility to the system.

Spectrum licences were introduced in the 1992 Act, and the first spectrum licences were issued in 1997. Spectrum licences confer leasehold ownership rights to licensees for fixed terms of 15 years. Overall, these spectrum licences cover a relatively small portion of the entire spectrum, but include the most highly valued bands. There are currently about 10 spectrum licensed bands.

Spectrum licences are typically 'service-neutral' and 'space-centric'. They permit users to operate any radiocommunications devices in a given 'spectrum space'[5] subject to respecting the requirements of a technical framework. Core conditions of the spectrum licence specify the band, the area, and the maximum permitted level of radio emissions outside its boundaries. Other conditions specify which transmitters are required to be registered to certify they will not cause unacceptable levels of interference outside the boundaries of the licence. Advisory guidelines assist

[4] Note that there were auctions of apparatus licences as early as 1994 and 1995.

[5] A spectrum space is a large band specified in terms of its underlying area, population density, terrain, prospective services and interference rights (receiver and transmitter). Once fully specified, the spectrum space allows a higher degree of freedom in usage and is generally favoured by large operators.

interference assessments between spectrum licensed devices and services operating under apparatus or class licences.

Spectrum licences have added much flexibility to radiocommunications management in Australia. But there are several areas of controversy such as licence renewal uncertainty and spectrum idleness in several spectrum-licensed bands. For example, spectrum licenses in the 500 MHz band (two way radio) have been little used, and some spectrum licenses in the lower 800 MHz band (mobile phones), 2.3 GHz and 3.6 GHz bands (broadband and WiMAX) have seen no or little network deployment.

Class licensing is a technology-centric approach to spectrum management that operates on an open and shared access basis. Class licences do not need to be applied for or issued to individuals, and in that sense are the equivalent of 'unlicensed' approaches in other countries. There is no exclusivity in usage and no fee to be paid. For these reasons, class licences are sometimes referred to as 'public parks' or 'open access' regimes. A class licence sets out some minimal operational conditions, which can include band, power, types of device and emissions, standards compliance, and geographic deployment constraints. Many class licences operate as non-interfering secondary usage easements in apparatus licensed bands or within shared bands such as ISM bands.

Since class licences are not issued to individuals, the licence conditions are not applied nor tailored to individual users. Class licences do not lapse, they continue until they are revoked or amended. Transmissions under class licensees are not allowed to interfere with other services and are not provided protection from interferences generated by other services. Thus, the spectrum access and usage rights granted through this regime are relatively basic and generally unsuitable for larger radiocommunications operators, such as telecommunications carriers with long-term infrastructure projects and quality of service obligations to their customers. The services and devices authorised under class licences are usually restricted to short-range, low-power applications.

The early liberalisation of spectrum access in Australia through spectrum and class licensing regimes has proved very successful, enabling the flexible adoption of numerous wireless innovations and a fast spread of broadband services [16].

THE MULTI-DIMENSIONAL REGULATORY SPACE

Taken together, these three licensing regimes allow the ACMA to provide flexible management responses to a large array of demands put on the spectrum. After all, due to its geographical isolation and its strong commitment to management reforms Australia has been at the forefront of spectrum management liberalisation for nearly two decades. The vigorous reform policies pursued by the SMA[6], the ACA and now the ACMA have transformed old bureaucratic rules into one of the most economically efficient, flexible and transparent licensing systems in the world.

Yet, there are still important challenges facing spectrum management policy in Australia. On the one hand there are limitations to the licensing regimes currently used and on the other hand the fast pace of technological development requires a continuous re-think of past arrangements and anticipation of future needs. The more flexible, adaptable and responsive the licensing structure is in meeting these challenges, the better the potential to fully exploit the regimes' potential, and efficiently deliver socio-economic benefits.

The three licensing regimes set out the rights and obligations of spectrum users in Australia. Although the licensing regimes differ in many respects, they also have common denominators. For instance, they all impose a minimal set of 'core' specifications about frequency, bandwidth, area, power and emission types, although the way these conditions are integrated in practice does vary. In general, apparatus and spectrum licensing have more in common than class licensing. Both provide some degree of exclusivity and interference protection in spectrum access rights. Both licences can be auctioned, leased or traded, and are subject to regulatory approval for licence renewal - though on very different terms.

Table I below illustrates the typical features of each licensing regime as a set of specific coordinates in a multi-dimensional space[7].

TABLE I
AUSTRALIAN LICENSING REGIMES - MAIN DIMENSIONS

Attributes	Apparatus Lic.	Spectrum Lic.	Class Lic.
Regime focus	Device-centric	Space-centric	Tech-centric
Exclusivity	Medium to High	Very high	None
Neutrality (T, S)	None to Moderate	Hi High	variable
Assignment by	Admin P, Auction	Auction	Not assigned
Individual assigned	Yes or No	Yes	No
Price / Fee	Admin P / market P	Market P	None
Tenure and Term	5 years/renewable	15 years	Unlimited
Interference protect.	Provided	Provided	Not provided
Rights certainty	Moderate	High	Low
Tradability	Moderate	High	Not relevant
Sub-division	Not allowed	Allowed	Not relevant
Coordination needed	High	High	Low
Coordination by	Regulator	Licensee	Tech-governed
Service neutrality	Usually none	High	High or low
Technical conditions	Basic	Complex	Basic

(T,S) stands for Technology and Service neutrality ; P stands for Price.

[6] The Spectrum Management Authority (SMA) was merged with the Australian Telecommunications Authority (AUSTEL) on 1 July 1997 to form the Australian Communications Authority (ACA), later to become the ACMA after merging with the Australian Broadcasting Authority (ABA) in 2005.

[7] Note that some apparatus and class licences will not correspond to this depiction, which, instead, attempts to describe representative licences.

Although the table focuses on 15 important dimensions, potentially, the number of dimensions characterising any spectrum management regime is much larger. By changing the coordinates taken by any regime in the multi-dimensional space (say replacing 'high' by 'low' degree of), one obtains theoretically another regime. Table I therefore suggests the existence of a near infinity of spectrum management regimes. Many of these potential regimes would present limited or no interest to regulators, but others would be of interest in specific situations. Clearly, there are more than just three options on the table.

Working with 15 dimensions is however not practical. Intermediary licensing regimes could be defined based on four key dimensions presented in table I [21, 22].

Service and Technological Neutrality, reflects the degree of licensee discretion in deciding which services to provide on the band, and in selecting and setting equipments standards. In Australia, several dynamic regimes are technology-neutral but service-rigid in practice. Neutrality is allocative efficient [5, 23] but may reduce technical efficiency by making coordination with other technologies difficult.

Band Exclusivity, describes the degree of exclusivity conferred to licensee rights. For instance, a very exclusive regime allows licensees (primary users) to negate access to any potential secondary users (right of exclusion). A very exclusive regime would also be expected to confer a high degree of rights certainty to licensees.

Rights Assignment, refers to the mechanism by which the selected regime transfers rights to licensees; price mechanisms (e.g. auctions), administrative pricing, arbitrary fees, or no assignment. This dimension might also distinguish between rights assigned to an individual entity or to a community at large.

Rules Coordination, determines the authority to set rules and protocols for efficient interference management. All licensing regimes require a minimum set of rules to keep interferences under check, but some regimes will grant a large degree of autonomy to licensees or users, other will rely on the legal system, and other still will rely on government authority.

Transferrability and liability, refers to the possibility to trade or lease frequencies. This dimension will include different variants of liability towards the regulator (and eventual harmed third parties) in case licenses are misused. In case the licenses are leased, this will range from the transfer of all liability to the lessee to keeping full responsibility for the use of the band with the lessor.

Following this nomenclature, the property rights regime consists of service neutral licenses and sharply defined exclusivity rights. Easements for secondary usage are subject to owners' approval and may need to be purchased. Interferences are managed among owners within a set of legal and technical rules. Expropriation would require due compensation. Licenses are fully transferrable and residual liability rights will be negotiated with the primary user.

Open access lies at the other end; no exclusivity rights, self-management of interferences under minimal government guidelines. Service and technology neutrality are tolerated to the extent that they remain compatible with the interference coordination rules (which may for instance require compatibility in technological standards). Licenses are not individually assigned nor can they be traded or leased.

DYNAMICALLY EFFICIENT INTERMEDIARY REGIMES

This simple model allows defining a set of dynamically efficient intermediary regimes for instance combining aspects of a property rights regime, with those of a C&C or an open access regime, as summarised in Table II. For instance, a common pool is a community of users operating under conditions of service and technological neutrality in a given spectrum band. The spectrum is shared access within the community, but rights are collectively-owned (and so more exclusive than under open access) and coordination rules are set and enforced by community management. If membership and sharing rules are decided by government, the regime may be described as collective command and control.

TABLE II
DYNAMICALLY EFFICIENT INTERMEDIARY REGIMES

Regime	*Neutrality*	*Rights*	*Assignment*	*Rules*
Private Commons	Flexible	FPR	AT	SC
Private Parks	Flexible	FPR	AT	SC
Public park	Flexible	CU	UB	GM
Collective C&C	Rigid	RCU	AL	GM
Common pool	Flexible	RCU	AL/UB	SC
Easement	Flexible	EPR	AT	GM
Market easement	Flexible	EPR	AT	SC
Regulated easement	Rigid	EPR	AT	GM
Eased C&C	Rigid	EPR	AL/AT	GM
Flexi-eased C&C	Flexible	EPR	AL/AT	GM
	Transferability	*Australian Examples*		
Private commons	High	:		
Private parks	High	:		
Public park	None	class licences		
Collective C&C	Low	Non assigned apparatus licences		
Common pool	Low	:		
Easement	Medium	MOST radio telescope on 843 MHz		
Market easement	High	Authorised under spectrum licences		
Regulated easement	Medium	Auctioned apparatus licences		
Eased C&C	Medium	Most apparatus licences		
Flexi-eased C&C	Variable	Some class and apparatus licenses		

C&C = Command and Control; FPR = Full property rights; EPR = Eased property rights, RCU = Restricted collective use, AL = Administrative licensing; AT = Auctioned licences and market trading; UB = Unlicensed band; SC = Self-controlled, GM = Government managed

A private commons is a similar arrangement worked out through a contract between the community of users and the band owner. A private park regime is a membership-based, fee-based licensing approach relying on device registration and self-coordination rules by users. In its operations, the private park is somewhat closer to a commons than a property rights regime, yet rights are individually rather than collectively owned.

An easement is a situation by which the government enforces secondary usage rights over the flexible rights held by primary users (e.g. telecommunications carriers). A regulated easement is a similar situation but in a context of service and technological rigidity such as where primary users' rights derive from a C&C regime. A market easement let these secondary rights be negotiated through markets rather than through government intervention.

C&C regimes can also be re-packaged, say to tolerate non-interfering easements for secondary users (Eased C&C) or grant service-neutral usage (Flexible C&C, similar to the regime governing the 'GSM' licences in the 900 MHz band discussed above) or both (flexi-eased C&C).

It is notable from Table II that Australia has most used intermediate regimes where government is the primary or a significant rule maker. These are enabled by different rules surrounding apparatus and class licensing. There has been a much narrower range of regimes used where the private sector has taken the lead. Theoretically spectrum licensing could enable many different regimes under private control. In practice, spectrum licensees have operated large systems and allowed very little or no use by third parties. The reasons have been much debated and have lead to several attempted expansions of the set of regulatory approaches.

For example, in 2001, the ACA made a submission to a Government inquiry [24], suggesting consolidation of the 3 licensing regimes authorised under the Act into one generic licence type. The generic licence would have enabled the ACA to build bespoke licences ensuring best fit between user, service and band [25]. This suggestion was not adopted although it was consistent with the object of the Act (as well as with the Principles for Spectrum Management that the ACMA adopted in 2009), which emphasizes both the quest for high-value allocation and efficient band usage.

Later on, and in order to increase dynamic efficiency in some frequency bands, the ACMA suggested issuing 'private park' licences for wireless access services (WAS). Future WAS needs seemed suited to a service-neutral regime authorizing any number and type of interoperable base stations in a licensed space with band coordination undertaken by users – in short a regime combining aspects of spectrum and class licensing. The ACMA contemplated issuing shared-use licences directly to users[8]. Furthermore, devices would be expected to use dynamic frequency selection techniques in similar fashion to class-licensed devices. Finally, there would be no seniority privileges, and no 'hard' licence boundaries - although base stations would have to be sited within the geographical area of the licence.

Since the enforcement of easements for secondary users in spectrum licensed space is effectively prohibited under the Act (even when the spectrum is permanently left idle by its owners), the private park regime was meant to induce more dynamic operations in what are currently spectrum-licensed spaces. In a Private Park, the definition of shared rights should induce users of similar size and background to coordinate and self-manage their services on different geographical spectrum spaces within the band [26, 27]. Although there is still regulatory interest in the potential for private parks to be a dynamically-efficient response to future WAS needs, Private Park arrangements have not yet been developed or implemented in Australia.

DSA TECHNOLOGIES, PROPERTY RIGTHS AND COMMONS

DSA technologies consist of a motley array of spectrum sharing techniques, driven by digital signal processing . The better known examples are (i) spread-spectrum and Ultra-Wide Band technologies, which spread non-sinusoidal signals over a wide frequency range at very lower power per frequency band, (ii) smart antennae, which represent an intelligent spectrum re-use technology cancelling interferences by spatial coding, (iii) software-defined radios, which process signals through general processors and can thus receive and transmit various types of waveforms by using different softwares (e.g. automatic frequency selection in modern radios), and (iv) cognitive radio, which builds on SDR technology to sense idle spectrum, analyses the vacant slot and its environment to decide whether to occupy it (in a 'listen before talk' logic) and once a decision is made, the radio guides prospective signals towards the unused spectrum.

It has often been argued in the policy literature on spectrum management that DSA technologies (often referred to as 'the technology') represent a great promise to expand the open access regime to much larger shares of the radio spectrum than it currently occupies [28, 29, 12]. In that perspective, open access is a dynamically superior regime to property rights, because the latter is inherently dynamically inefficient by force of being too exclusive and therefore entailing high transaction costs for secondary usage. Incorporating power limits and listen-before-talk protocols into the hardware reduces transaction costs between negotiating parties to their bare minimum. Open access and collective ownership also induce collaboration and generally offer much more favourable terrain for innovation [30]. Without commercially deployable DSA technologies though, the threat of interference and 'tragedy of the commons' outcomes is conspicuous for higher power services such as broadcasting and WAS where there is a need for coordination to minimise

[8] Note that spectrum licenses in principle authorise their owners to operate a similar regime, since spectrum spaces can be subdivided, and traded or leased to third parties on owners' conditions. However, the private park is initiated by government, and seeks commons-like coordination rules within the park rather than hierarchical property-based rules. Such a regime has not arisen under the management freedoms granted spectrum licenses.

interference. There is general agreement that open access is currently a very successful way to manage short-range, low-power applications. However, suitably designed and commercially operational DSA technologies are a necessary condition to expand open access to different types of applications.

Economists and other proponents of the property rights regime argue that open access is therefore too dependent on the promise of DSA technologies[9]. Cognitive radio technology still has to clear important barriers if it is to contribute significantly to dynamic spectrum usage. The difficulties of sensing idle spectrum in the presence of geophysical obstacles, the 'hidden terminal' issue, doubts about the cost-effectiveness of these technologies,[10] indicate just how complex the way ahead is. As is well known, software-defined radio technologies have been discovered and used by the US Military for many decades. The fact that they are filtering very slowly and very selectively from the military to the civilian domain and are still not widely available for most civilian radiocommunications applications illustrates the uncertainties for regulatory planning.

Ultra Wide Band is a much less complex matter since the technology is available and already operational in many places, usually under an unlicensed arrangement (i.e. a class licence in Australia). However the matter of interference with devices operated under other technologies in a confined space remains open. Past controversies about the legally acceptable noise floor of UWB devices have generated a lengthy legal process for UWB authorisation in the US [32]. Australia, New Zealand and EU countries have since authorised some UWB applications especially for imaging, vehicular radar and home-networking applications. Higher power applications such as ground-breaking radar remain in doubt. Yet, the relative success of UWB technology does not solve much. Because it trades so much power for bandwidth, UWB applications are short-range, just like Wi-Fi, and so UWB provides no gateway for an open access regime of a very different nature to Wi-Fi. In particular it offers little promise for high power communications applications.

Without ready-to-use DSA technologies, open access does not represent a credible solution beyond the short-range devices it currently authorises. What is more, even if DSA technologies were fully operational, the very strength of demand for wireless applications is growing at such a pace that DSA technologies would only realistically offer a short-term patch-up to current bottlenecks.

By contrast economists emphasise that the property rights approach efficiently *does* solve excess demand through pricing and access rationing. Assuming the price mechanism operates without distortions, these instruments guarantee that excess demand remains under check (market imperfections leading to price distortions remaining the matter of government regulation).

Furthermore, the property rights approach can *also* make efficient use of DSA technologies, as these technologies enable spectrum owners inclined on spectrum trading to find more efficient ways to let secondary users access and use their bands. Gerald Faulhaber neatly concluded this argument by stressing that '[DSA] technology is neutral regarding the overarching legal regime' ([13] p. 268).

Economists have also questioned whether Wi-Fi and similar unlicensed experiments might not in fact represent a repackaged property rights approach in which rights are defined over the coverage range, with large operators (e.g. universities or airports) securing exclusive rights over specific areas [33, 16]. In that sense, unlicensed approaches do not quite provide open access, but merely redefines access rights in a different way.

These arguments and counter-arguments have led to a stalemate between partisans of the most dynamically efficient solution and those of the most economically rational (and allocative efficient) solution. However, this debate has almost turned satirical. Even without DSA technologies, open access has indeed proved successful in some areas (e.g. Wi-Fi on 2.4 GHz) but disappointing or disastrous in others (e.g. US U-PCS bands on 1.9 GHz, or U-NII bands on 5.2 GHz and many more). Similarly, the property rights regime in Australia has seen significant network deployment and spectrum trading on ITU designed mobile phone bands (800 MHz, 900 MHz[11], 1.8 GHz and 2.0 GHz). Other bands have shown significant trading, but band idleness has been quite common. Licensees in all bands have shown an almost universal reluctance to allow secondary use [22, 34].

It seems the property rights approach has not so far provided an avenue for dynamically efficient spectrum usage by multiple users. The experience in Australia is that spectrum licences (which confer property rights[12]) have generally been quite successful in technical and allocative terms, but they proved to be very monolithic. They occupy large portions of spectrum in very exclusive ways. Although spectrum licences

[9] Note that the inverse argument is often heard in the industry. According to this view, the commercial deployment of DSA technologies will only become interesting with the regulatory organization of a spectrum management system that is heterogeneous and dynamic rather than one that is homogeneous and proprietary. We contrast these views in the next section.

[10] See for instance [31] p. 7-13 and [13] p. 265 for a discussion. Most of these problems have solutions but they require some kind of return to command and control type interventions.

[11] As stressed earlier, the 900 MHz band has not been spectrum licensed and represents a unique example of Flexi C&C regime, with some degree of technological neutrality and similar trading and leasing rights to spectrum licenses, albeit with much less formal certainty in the duration of the access rights.

[12] Legal scholars might dispute that leasehold constitutes property since it that regime, the ultimate owner remains the Government.

were designed as a tool to allow market function, the large spectrum-licensed spaces they control are monopolised by the high spectrum-consuming technologies deployed on these bands. Can licensees realistically be expected to allow large amounts of secondary use, while their primary goal is to guarantee a quality of service for their prime network? Under these conditions, some degree of regulatory action may be needed to increase the yield of spectrum-licensed spaces by allowing non-interfering secondary usage by low-power, spread-spectrum or UWB devices. This suggests an important role for intermediate legal regimes to allow DSA technologies. The challenge for regulators is to set up intermediate regimes that retain the benefits of a market driven property-rights approach for the primary allocation.

DSA TECHNOLOGIES AND ALTERNATIVE REGIMES

DSA technologies are a plus for any management regime. The question is which regime presents the best environment for their full use. We argue in this article that intermediary regimes would better respond to this promise because they are focused on improved access (thus addressing the matter of exclusivity and idleness) while still limiting the number of users in various different ways (thus addressing the matter of congestion and tragedy of the commons).

By contrast, the problems of excessive exclusivity and low usage that can be presented by a property rights are not resolved by DSA technology. If an owner is opposed to secondary usage because she does not accept that managing other users is part of her core business, the presence of new technologies may do little to change her resolve.

Similarly, the problems of excessive interference, overcrowding and quality of service under an unlicensed (class licensed) approach may not be solved for long with the adoption of properly working DSA technologies. Additionally, there are many situations where tragedy of the commons can arise even with properly working DSA technologies—see for instance ‘greedy design’ arguments discussed in Refs. [35, 36]. Unlicensed approaches raise issues of compliance with shared-used policies, of secondary usage coexistence with primary licensees, and the potential matter of technological supremacy (e.g. the WiMax debate).

The importance of having as many alternatives available to manage the spectrum in a dynamically efficient way is well recognised by most experts. In his discussion of the standard government-imposed easement model suggested in ref. [37], Martin Cave recently stressed that ‘it is unlikely that there will be a corner solution with the same regime optimal in all frequencies’ ([19] p. 230). Other proponents of the property rights approach would agree. William Baumol and Dorothy Robyn for instance add that ‘any good rules will have to be readily changeable as demand, used, technology and any other critical determinants evolve in unpredictable ways…Rather , redesign of the current spectrum governance regime has been discussed in terms of the choices between two fundamentally different alternatives’ ([33] p. 3).

Intuitively wireless applications that require guaranteed spectrum access at very short notice (e.g. emergency services) will require a different treatment than services operated on a continuous basis (e.g. broadcasting), or those that require guarantees of long-term access to justify large investments in infrastructure and market development (e.g. third and fourth generation networks). There is an endless list of services, technologies, users and markets all with different priorities and requiring different types of rights.

Thus, what this debate misses is recognition that there are many more choices than just open access and property rights, that these additional regimes are an important addition to the debate, and that they also can make optimal use of the opportunities offered by DSA technologies. Since these regimes are inherently more dynamically efficient, by encouraging an increased number of users on any given band, it would be intuitive that their combination with a set of operational DSA technologies would conduce to better economic outcomes. What benefit is a technology such as cognitive radio if it is not used due to a legal impasse (say because a spectrum owner is concerned for the quality of service of its networks), or if demand is such that the spectrum is permanently congested?

Intermediary regimes show the way ahead to remedy these likely shortcomings, and they are all well designed to make best use of DSA technology. For instance, if spectrum owners such as 3G network operators were required (rather than merely authorised at the moment) to manage their spectrum as a private commons, it is likely that this would take place by widespread adoption of spread spectrum and UWB technologies, since, as discussed earlier the amount of bandwidth required to operate a 3G network would leave little room for secondary users (except for less dense geographical areas, where traffic can be quiet for long periods of time). Cognitive radio would be just as welcome since the large bandwidth needed in a 3G network is nonetheless not permanently used, nor in all geographical locations.

This could be done under an easement model by providing legislation that allows non-interfering devices to operate under a certain noise floor level, as was the case with UWB in the US. This process can prove controversial (and has been in the US where no real property rights existed).

A softer approach is to encourage the establishment of private commons. How does one induce a spectrum owner to run a private commons? Regulators may create a structure of private incentives such as a scale of rights based on spectrum usage (low usage implying later demotion to a lesser rights regime). On this basis, a spectrum owner that makes little use of the resource can nevertheless keep ownership rights by operating a private commons. A private commons would differ from an easement model in that the owner selects secondary users rather than have coexistence imposed by regulatory rule. Alternatively, if these reforms prove intractable, the Government may want to keep some spectrum licences for itself to encourage the development of private commons.

The private park is a different matter, since the requirement to collaborate with different users is in-built from the start, and is therefore not premised on any easement conditions. A private park licensee would know up-front that its shared-space licence would make optimal use of the spectrum through sharing between co-owners and extensive use of DSA technology. In the private park, idle spectrum detected, say by cognitive radio, can be readily used since the individual licences would authorise shared use. Devices registration and an upper limit on the number of park owners (based on underlying market for the likely services and population density in the geographical area considered) would help guarantee quality of service. The common pool approach does not differ markedly from the private parks as far as the use of DSA technologies is concerned, the main difference residing in joint rights ownership rather than shared private rights.

Public parks and device parks by contrast are quite widely operated for services that are not severely affected by quality of services issues. They are often conflated with the open access regime (which assumes much less regulatory intervention than observed in these parks). They make intensive use of spectrum sharing technologies on a coexistence basis, i.e. equipments are built to avoid interferences but in most cases devices do not communicate with each other.

Finally, eased and flexi-eased C&C regimes also facilitate the adoption and the potential use of DSA technologies, by preserving some degree of regulatory discretion to introduce spectrum sharing in bands that are mostly fallow. Because users rights are less extensive and less certain than under property rights, these regimes are less ideal for services requiring important infrastructure investment.

Two fundamental features define each of these intermediary regimes; (i) whether they are premised on collaboration or coexistence, and (ii) whether users are endowed equal or hierarchically-defined rights [38]. The private commons is collaborative but hierarchical while the private park is collaborative but egalitarian. Similarly, the coexistence of the public park is egalitarian while the coexistence of the easement model is hierarchical. The eased and flexi-eased models are also hierarchical.

Collaborative models will require much stronger sharing protocols (and institutions to enforce them) than, say, the current equipment standards used for Wi-Fi. And so collaborative approaches will be harder to integrate with DSA technologies than coexistence models. Egalitarian approaches will be more flexible and more dynamic than hierarchically-defined regimes because they reduce or remove the authorisation requirements of the latter, but they should be restricted to services with limited users to mitigate against tragedy of the commons outcomes, and where quality of service is not a major issue.

Practical Impediments to Regulating DSA Technologies in Australia

The emergence of DSA technologies provides a challenge to the Australian radiocommunications licensing system set up by the passage of the 1992 Act. The Act provides sufficient flexibility for the regulator to licence DSA technologies in some circumstances but a more comprehensive licensing toolbox may enable better solutions.

To provide an example of legal/regulatory hurdles facing regulators in the usage of DSA technologies (beyond authorisation issues), consider the following hypothetical case. Theoretically ACMA can issue class licences on a band prior to the band being specified for spectrum licensing. The design of the class licence may well be based on assumption about cognitive radio developments over the next 15 years. Yet, once the band is specified for spectrum licensing, it becomes very difficult to for the ACMA to amend the class licence because the Act significantly constrains the ability of the ACMA to do so once a band is specified for spectrum licensing[13]. So, if cognitive radio happens to behave differently than expected there may be several long-term regulatory problems to solve (e.g. spectrum licensees complaining about not having the usage rights – such as quality of service rights – they expected to obtain).

The widespread adoption of DSA technologies may well require a re-think of the entire system of registering licences and assigning new services. The regulator maintains the licence register to contain all the data required to assign new licences so that they do not interfere with existing services. Searchable fields, including centre frequency, bandwidth and site location allow almost automatic frequency assignment of traditional radiocommunications services. However, as currently specified, the register does not contain all details that would be needed to assign systems (whether DSA or not) in a DSA environment. While DSA systems are a rarity over most of the spectrum, they can be accommodated as exceptions, but greater sophistication will be required as DSA becomes common.

A third regulatory challenge arising from the widespread adoption of DSA technologies will be the pricing of spectrum. More sophisticated auction methodologies may be required to efficiently allocate spectrum for use by DSA technologies and systems that do not absolutely deny spectrum to other services but do impose constraints on those other services. Administratively set prices also will need to be set in a more

[13] Strictly speaking, frequency bands are either designated or declared for spectrum licensing depending on the particular legislative pathway used.

sophisticated way to allow for the impact of DSA technologies and systems.

INTERMEDIATE REGIMES UNDER CURRENT LEGISLATION

The dynamically efficient intermediate regimes identified earlier may be licensed in the following ways in Australia.

TABLE III
LICENSING INTERMEDIARY REGIMES IN AUSTRALIA

Regime	*Licence system*	*Ownership*	*Current status*
Private commons	spectrum	common	allowed-unused
Private parks	spectrum	single	allowed-unused
Public park	class	..	commonly used
Collective C&C	apparatus	common	commonly used
Common pool	apparatus/class	common	unused
Easement	spectrum	single	partly allowed
Market easement	spectrum	easement	rarely used
Regulated easement	spectrum	easement	commonly used
Eased C&C	apparatus	easement	commonly used
Flexi-eased C&C	apparatus	easement	commonly used

The private commons regime ideally arises when a group of access seekers collectively own a spectrum space and operate within it according to rules of there own devising. However, a private commons has not been tried in Australia. There has been no interest from spectrum users and there are doubts about the practical aspects of property rights to spectrum held by tenants in common basis. However, the regime is allowed by the Act; it just requires a coalition to jointly purchase a spectrum licence and run it as a commons.

A private park is a similar concept, but where ownership of a spectrum licence is held by a single licensee (which may be collectively owned), which operates access on commons basis. This is allowed under the current regime; it requires a licensee to issue third party authorisations to other spectrum users. There has been no take up of this approach in Australia with anecdotal reports that spectrum licensees are reluctant to enter into third party authorisations.

Interestingly, it is the case that the apparatus licence arrangements in the 2.5 GHz band and the collaborative operational practices of the television broadcasters who hold those licences have arguably produced an outcome that has some of the attributes of the private commons and private park regimes.

A market easement is an easement to a spectrum licence where the details of the easement are controlled by the spectrum licensee. This is allowed in Australia by way of third-party authorisations to spectrum licences. The degree to which this type of arrangement is used is not known but many access seekers have reported dissatisfaction with the difficultly of negotiating such arrangements. The ACMA has identified impediments to third party authorisations, which it is addressing.

Collective command and control is commonly used, for example in non assigned apparatus licences. Public parks are the extensively used class licensing regime.

Different types of easement to a spectrum property right regime are allowed under current legislation, although few of them allow to 'enforce' an easement upon a spectrum licensees. For instance, the ACMA is allowed to issue apparatus licences in spectrum designated for spectrum licensing under special circumstances; or to defence, law enforcement and emergency personnel. In the normal course of events an access seeker to an easement to a spectrum licence is expected to negotiate a third party authorisation from the primary licensee. The alternative, of an easement by way of an apparatus licence under special circumstances has been used in a small number of cases such as short-term trials of equipment.

Class licences issued before spectrum licensing processes commence are also able to continue after spectrum licences are issued but this approach has not been used by the ACMA.

Collective command and control arrangements are used extensively in Australia. Here flexible rights are granted for restricted collective use under an administrative licence. Apparatus licences are granted for two-way radio systems that can be used anywhere in Australia (or in a State). The service is not flexible, but the technology can vary, digital or analogue for example, provided the channel width is adhered to. Many systems are licensed on each channel used for this purpose and licensees are expected to coordinate with one another on a no interference no protection basis. These licences are commonly held by companies that provide two way radio services to sporting or cultural events.

The related common pool regime, where coordination rules are set and enforced by community management has not been used in Australia.

A regulated easement is an easement under a command and control licensing arrangement. This is a quite common arrangement. Class licences are issued underneath apparatus licensed bands, with usually only power restrictions on the operation of devices under the class licence.

Eased command and control and flexi-eased command and control are also common in Australia. The degree of neutrality in both apparatus and class licences can vary considerably, and both allow easements. For example, a class licence may specify both a power level and a service (e.g. wireless microphones or only a power level). An apparatus licence may specify a service and a technology, or only a service.

EXTENT OF USE OF DSA TECHNOLOGIES IN AUSTRALIA

The extent of DSA technology use in Australia is currently limited. The Jindalee over-the-horizon radar is a high profile example. This system developed in Australia for defence and security purposes roams over the HF band avoiding interference to some users on a dynamic basis and avoiding sensitive bands all together.

UWB for ground penetrating radar has been authorised by a non assigned apparatus licence. The licensing of these systems posed a number of problems for the Australian regulator. These systems operated over bands designated for spectrum licensing and legislation prevented them from being authorised by a class licence. Apparatus licences could have been issued to individual licensees but would have had to pass the test in legislation of being special circumstances to coexist with the spectrum licences. Also the current apparatus licence fee schedule does not make allowance for sharing, and the standard formula, where fees are proportional to bandwidth, would have resulted in a very high fee.

The fee formula causes other distortions to the way systems are licensed. Space licences for communicating with satellites are sometimes issued to a company that leases transponder capacity on a satellite owned by a foreign operator, which for reasons of its own does not wish to apply for licences itself. The licensee may only use 27 MHz bandwidth at any one time but the centre frequency may vary over 500 MHz, depending on the transponder used. These are typically licensed as a 27 MHz band width system, with a frequency at the centre of the 500 MHz range. This provides an appropriate fee, but it provides little guidance to the actual frequencies used. If this practice became widespread with DSA technologies, the use of the register of licences for frequency assigning would rapidly diminish.

A number of DSA technologies, such as cognitive channel selecting technologies, are already authorised by class licences. Examples include WiFi, DECT cordless telephone systems, RLAN point-to-point backhaul links used to connect RLAN and broadband networks to other networks on 5.8 GHz, as well as biomedical telemetry technologies such as medical implant devices operating on a number of bands under the Low Interference Potential Devices (LIPD) Class License.

Australia's regulatory readiness for DSA

The readiness of the Australian regime to deal with the extensive use of DSA technologies is like the proverbial curate's egg—good in parts and therefore unsatisfactory as a whole. Consequently, it needs reviewed in its entirety to provide the most efficient regulatory outcomes.

The apparatus and class licensing regimes can be readily adapted to deal with DSA technologies. In deciding whether to issue an apparatus licence, the Act specifies that the ACMA must take into account the effect on radiocommunications of issuing the licence. Class licences may be issued to manage the spectrum in bands not subject to spectrum licensing. It is a simple administrative matter for the regulator to authorise DSA technologies under apparatus or class licensing. The regulator may specify sharing conditions and technology standards to enable their effective use.

Spectrum licences were established in the Act as a market-based system of spectrum management. In order to provide explicit rights of spectrum access, coexistence of other licences over the same spectrum space as spectrum licences was very restricted. It was thus established as a pure property rights regime with no flexibility for the regulator to experiment with intermediate solutions. The regulator has little discretion to allow DSA technologies; they can only be introduced by agreement with the spectrum licensee.

As mentioned above, there has been a marked reluctance by spectrum licensees to allow access by secondary users. This has the potential to severely restrict the efficient use of DSA technology over important parts of the spectrum.

If Australia is to fully benefit from the transformational potential of DSA technologies, it will need a review of the legislative provisions surrounding spectrum licensing. This will be no easy task. Market-based reforms of spectrum management in Australia have been very successful on the whole. It will require ingenuity to develop a robust reform package that keeps the benefits of these reforms, while enabling the efficient use of DSA technologies.

Conclusions

Thanks to legislative reforms in the early 1990s, Australia already has much discretion in the design of its radiocommunications licences. However, this resilience was developed within the legal boundaries of a trichotomic licensing regime, not through the expanded discretion offered by a bespoke licensing approach. Some intermediary regimes, such as Flexi-eased C&C (a C&C ancestor to spectrum licences) have been used quite successfully. Other regimes, such as private parks and privately-run commons (offshoots of spectrum licences) are authorised regimes under the Act but have seen no or little action in practice.

Potential regulatory solutions to the issues raised in this paper include wider adoption of intermediary regimes identified in the previous sections. Implementing these regimes with a set of ready-to-use DSA technologies could help resolve the stalemate between too much exclusivity (i.e. spectrum idleness issues) and excessive usage (i.e. quality of service issues). However, as discussed, some of these regimes are not yet authorised under the Act. Those intermediary regimes that could be implemented without legal amendments (e.g. the Private Parks) may need to be further promoted among stakeholders. Those regimes which are not authorised under the Act (e.g. enforced easement to spectrum-licensed spaces) may need the development of a new set of legislated rules.

The more flexible, adaptable and responsive the regulatory framework, the better it will be in rising to the challenges that will increasingly confront spectrum policy makers. In turn, this will improve the allocative, dynamic and technical efficiency of the radiofrequency spectrum. In particular, the development and implementation of a more sophisticated approach to licensing regimes will allow the effective and efficient exploitation of more sophisticated technologies such as DSA.

To conclude, the Act was designed to provide an efficient regulatory regime for the conditions applicable or anticipated at the time it was passed in 1992. The Act has coped admirably with challenges that have arisen in the intervening 18 years. However, it seems clear that a review of (at least) the licensing regimes established by the Act has the potential to significantly increase the efficient allocation and use of the radiofrequency spectrum in Australia by transformational technologies such as DSA.

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