GSR Discussion paper

New frontiers in Spectrum Licensing

Work in progress, for discussion purposes

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1 NEW FRONTIERS IN SPECTRUM LICENSING

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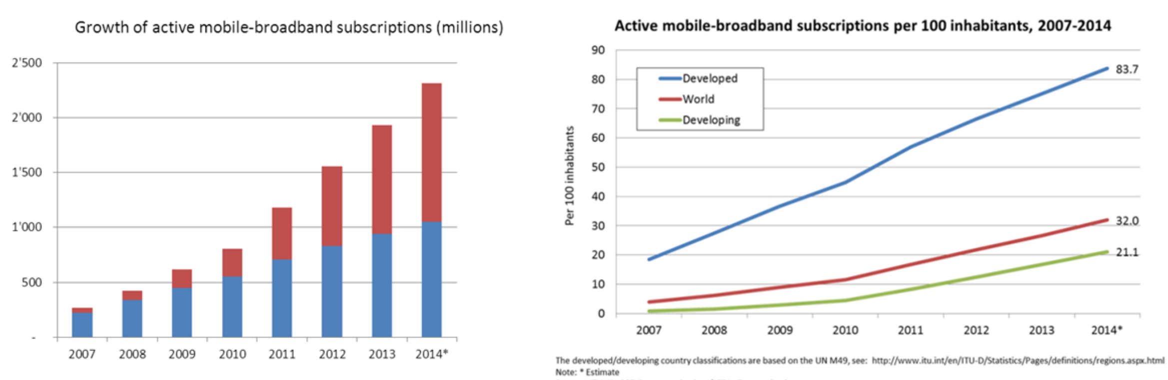
1 Introduction: Regulators under Pressure

Spectrum managers in countries around the globe today face strong pressure to free up access to more spectrum for broadband wireless network access. Prompted by a sharp and accelerating rise in wireless broadband subscriptions in many countries (See Figure 1), regulators are scrambling to find more spectrum for the wider channels and greater throughput available with advanced wireless technologies such as Long-Term Evolution (LTE).

In responding to the need to utilize spectrum for the public good, regulators look to – and act through – the ITU, where the process of satisfying spectrum requirements for wireless broadband plays out, culminating in frequency allocation decisions at World Radiocommunication Conferences (WRCs). National authorities (governments and/or regulators) then allocate spectrum nationally and license it to network operators. In addition, regulators can deploy flexible licensing options to meet the need for more spectrum, taking advantage of emerging technical solutions for sharing spectrum.

In the context of ITU's framework for spectrum allocation – which is building toward a WRC in November 2015 – regulators and telecommunication manufacturers and operators are exploring ways to accommodate new broadband spectrum access while not harming incumbent services. Along with this, in an effort to find solutions to share existing spectrum, some policy-makers at the national level are now exploring new approaches to spectrum licensing. As a result, some old certainties and assignment methods that were based on clear lines between licensed and licence-exempt frameworks are beginning to blur – with potentially uncertain results. Database and sensing technologies are driving opportunistic sharing, challenging current licensing conventions.

Figure 1: Growth in mobile broadband, 2007-2014



Note: * Estimates
Source: ITU World Telecommunication /ICT Indicators database

This paper looks at this exploration, now under way in some countries, about how to accommodate broadband spectrum expansion while not obliterating incumbent spectrum uses. This is an examination of new approaches such as *licensed shared access* (LSA) or *dynamic frequency selection* (DFS), which in some ways build upon the more-established success of unlicensed, short-range and low-power devices (i.e., Wi-Fi) and the less-established "white spaces" systems.[1] These sharing-based approaches may be useful complements to existing options, such as spectrum auctions, tender processes and spectrum re-farming, which have been used to award spectrum in cases where there are multiple applicants for the same spectrum.

This regulatory discussion is also about the use of "small cell" and "local area" network topologies to augment traditional mobile cellular networks. And in the near future, this debate will focus on using cognitive radio systems to "sense and avoid" other transmitters in a dynamic, real-time way.

The various experiments in sharing and spectrum management explored in this paper prompt several real questions. How practical are these sharing innovations in many countries, and how should regulators protect rights of use and access – the traditional rationale for spectrum licensing – for all users who need that access? These questions are just now being explored. But there is a broader question: Are such fluid sharing and licensing strategies really needed – and if so, where and in what circumstances?

2. The Evolution of Spectrum Licensing

It is common to perceive of spectrum as real estate, with spectrum management taking on the role of land management. In this analogy, allocation becomes a form of zoning, and a licence becomes a kind of spectrum deed or lease agreement. The holder has certain rights of usage, which are determined and articulated in regulations, licence terms or concessions. The government retains some of the spectrum for its own uses, and it even may set aside some spectrum "land" for the public good – a sort of spectrum "park" for everyone's common use. Spectrum with good propagation characteristics is often called "beach-front property" because of its high utility for mobile services, broadcasting and other important uses. The analogy of spectrum to land is so useful that in many ways, it has come to influence the very way we envision spectrum and how it is used.

Some spectrum engineers and policy-makers, however, have come to view the acreage analogy as overly limiting. In their view, thinking of spectrum as a static resource or commodity is not helpful in a policy environment that increasingly emphasizes ways to squeeze more usage out of the same laws of physics. After all, radio-frequency spectrum *isn't* land. It is a means of transporting radio frequency energy, in the form of signals, from transmitters to receivers. One cannot mine spectrum. It cannot be trapped, saved, contained, transported or stored. Spectrum will never be "used up" or exhausted. It is not even Earth-bound (we are now receiving signals from a 36-year-old space probe, Voyager 1, at the very edge of our solar system).[2] On the other hand, there is no doubt that spectrum is a natural resource that is limited in terms of amount of usable frequencies and the number of users having access to specific frequencies.

Perhaps it's helpful to think of spectrum in terms of resilience and agility. In other words, the best way to approach spectrum is by exploring and pioneering better ways to transmit and receive signals among more users without disrupting one another's messages. Rather than being about ownership (tacit or otherwise), spectrum management is properly a task of increasing *access* while avoiding *harmful interference*. The hope is, increasingly, that science, regulations and technology will help deliver on that task.

2.1 Current Spectrum Assignment Models

Before exploring the new experimentation in spectrum licensing, however, it might be useful to review how spectrum is currently assigned and how those methods evolved. This is important, because in many ways, new ideas about spectrum licensing represent an evolution from existing frameworks.

A 2012 ITU paper on spectrum value and valuation defined several broad perspectives on spectrum assignment and usage:[3]

- The *administrative licensing* model -- Most often employed for (but not limited to) government spectrum usage, this command-and-control approach entails determining the spectrum requirements of public-service or administrative agencies -- including law enforcement/public safety, military, science or infrastructural requirements – and simply making assignments in the appropriately allocated bands. This model is also used whenever the demand for spectrum can be handled on a first-come-first-served basis, as for radio relays, professional radio or satellite earth stations. In this case, annual fees may be charged to the users to cover the spectrum management costs and/or reflect the value of spectrum.

- The *flexible rights-of-use* model -- This model adopts an inherently economic perspective on spectrum licensing, letting the market determine the value of spectrum through auctions and secondary markets, offering to licensees the flexibility to use the spectrum in the most economically rational way.

- The *licence-exempt* model – Taking advantage of low-power, short-range transmitters, the licence-exempt model treats spectrum as a public "commons" that can be used and shared without licensing it. However, this model does not imply that unlicensed devices can operate in an unrestricted way – they are not "unregulated." They must comply with a set of detailed technical and operational specifications, often listed in so called "general licences" or "class licences," in order to enable compatible use of a frequency band by the same or different radiocommunication services.

While these models represent distinct philosophies about what spectrum is and how it can be used, they are not mutually exclusive. In fact, most countries' spectrum management regimes are pragmatic combinations of all three approaches. The administrative licensing model is the baseline practice, having been in place before the other two approaches were defined. It is still employed for many types of uses, whenever the demand for spectrum can be handled on a first-come-first-served basis. In such cases, governments generally levy fees on private-sector licensees (a process known as "administrative pricing') for the use of spectrum and/or to cover the spectrum management costs.

For commercial wireless services, however, many governments have made spectrum available through licensing, giving licensees rights of use (most often exclusively) for a set period of time and subject to delineated conditions. Cellular mobile network operators are, of course, the most common examples. The flexible right of use model, however, commonly comes into play in licensing whenever there are more potential users than there are channels or licences to be distributed. Some form of auction or tender process can then be used to determine the economically best-situated applicants for those limited licences.

Table 1 -- Applications of the Three Spectrum Distribution Models

Model	Typical Users	Typical Uses
Administrative Licensing	• Government agencies ▪ Military ▪ Public safety ▪ Resource managers ▪ Transport operators • Broadcasters • Professional users • Earth station operators • Fixed Telecom infrastructure operators	• Radars • Aeronautical and maritime • Tactical radios • Remote sensing • Terrestrial Television broadcast-ing • Professional mobile radio • Point-to-point links • Satellite telecommunications
Flexible Rights of Use	• Commercial terrestrial wireless operators • Satellite operators	• 2G, 3G and 4G mobile services • Satellite broadcasting and telecommunications • WiMax or fixed wireless
Licence-exempt	• Internet hotspot providers • Individuals	• WiFi (WLANs) • Other Low-power devices (key fobs, garage openers)

Finally, governments have increasingly established modes of licence-exempt or class-licensed usage for a wide range of consumer devices, ranging from automobile key fobs up to Wi-Fi "hot spots" – and everything in between. Wireless routers, baby monitors and hotel wireless networks all function on the unlicensed/commons model, usually in discrete bands set aside for unlicensed usage (these may include bands in the 900 MHz, 2.4 GHz and 5 GHz ranges).

At a global level, there has been some exploration of how incumbent services can be protected while sharing spectrum with some of these limited-range consumer devices. At the World Radio-communication Conference in 2003 (WRC-03), for example, the ITU opened up the possibility to use parts of the 5 GHz range for wireless local area networks (LANs), with portions of the spectrum being shared with radars in the incumbent, primary radiolocation service. This was the first example of a cognitive radio, established through a technology known as *Dynamic Frequency Selection* (DFS) (See Section 3.2.4). It also foreshadowed the concept of allowing, under controlled circumstances, *dynamic spectrum access* (DSA) to radio-frequencies by unlicensed devices. This early experiment in

DSA, however, yielded mixed results. Interference problems were reported as a result of unlicensed equipment operating with disabled DFS capability.

2.2 The "Pros" and "Cons" of Current Assignment Models

Perhaps it is time now to take stock of the conventional wisdom about these three assignment approaches. Have these models, mixed and matched and applied in various combinations, led to optimal uses of spectrum? How could they be tweaked or even overhauled to achieve better results?

2.2.1 First the "Pros"

As a threshold analysis, it is worth noting that the very **pragmatism** of most current assignment regimes may well be their greatest strength. Put simply, it seems to make sense to apply different assignment strategies to different types of uses. For example, the operating characteristics of most equipment used on an unlicensed basis obviate the need to require a licence. These characteristics include low power, short range, and use in bands where they can only interfere with each other and are allowed to operate only on a non-protected basis. It makes little sense from a practical standpoint to license every consumer product that uses radio frequencies to function under these conditions. Governments certainly have an interest in type-approvals and equipment certifications to ensure that these operating characteristics are met. But this can be essentially opaque to the consumer, who just needs to find the correct size of batteries to become a "wireless operator" – at least of their own mobile phones or netbooks.

By the same token, requiring large, often multinational corporations to pay a market-based price for one of their most necessary operating inputs (i.e., spectrum) also makes sense. From the government's perspective, operators are less likely to waste or "warehouse" spectrum if it does not come cheaply or in overwhelmingly large supply. Moreover, it would be irrational from a business perspective for an operator to pay more for such an input than it could earn through providing the eventual output (the telecommunications service). So, attaching the proper economic value to spectrum allows operators to make rational decisions about how to use the resource most efficiently and effectively. (This issue is discussed in detail in ITU-R Report SM.2012 "Economic aspects of spectrum management," which analyses financial and economic mechanisms that contribute to effective management of frequencies and spectrum efficiency.)

Meanwhile, if governments expect operators of capital-intensive networks to make sufficiently large, long-term investments in spectrum and network construction, it makes sense to grant spectrum access rights on an exclusive basis – i.e., within a certain spectrum band and in a particular geographic area. Thus, the property rights model is conducive to providing large operators the kind of stability and predictability that they need to invest in market entry.

Another advantage of current licensing approaches is that they generally provide regulators with sufficient tools to make and enforce decisions on **market structure and interference management**. The administrative licensing model, naturally, represents the most rigid framework (in the past it was sometimes characterized as "command-and-control" licensing) for allowing some uses and disallowing others. Most governments feel they need to maintain direct control over a certain amount of spectrum in order to facilitate some uses that would be impossible or un-economical for the market to provide, but that are necessary or important for the public good. With regard to commercial licences, regulators can use their licensing power to release an optimal amount of spectrum into the marketplace, and they can influence operators' behavior through the ability to amend or revoke those licences or the regulations that govern them.

One of the advantages of the individual licensing model is that it provides regulators with information on the usage of specific frequency bands. This allows the establishment of national databases containing information on the frequency assignments that have been made to operating stations. Such databases assist in interference management and in preventing unauthorized or abusive use of frequencies. They may also represent a critical element for dynamic spectrum access technologies, as this paper will explore in Section 3.

In addition, many licensing regimes now have built-in **flexibility**, because they provide for technology neutrality, service neutrality and unified licensing. Earlier, command-and-control licences prescribed exactly what service could be offered, using exactly which technology. As part of "lighter touch" regulatory reforms, however, regulators often refrain from such prescriptions. They may even issue licences that allow recipients an open-ended choice to provide service using a combination of wireless and wireline technologies (i.e., unified licensing). These innovations enhance the general pragmatism of many updated spectrum management regimes.

So an important conclusion is that licensing regimes based on the existing approaches to spectrum assignment continue to function in many ways and in many countries. For regulators, these licensing regimes provide a useful toolkit for planning, allocation and assignment of frequencies in ways that respond to their market realities.

2.2.2 Then the "Cons"

Perhaps the biggest drawback of current spectrum licensing regimes may be that, in the face of perpetually accelerating usage demand in many economies, they may not be pragmatic or flexible *enough*. This critique points to spectrum in the critical bands below 6 GHz and sees gridlock. Through administrative assignments to government agencies, many bands are often used by governmental and public applications, which may not always be spectrum-efficient.

The legacy of commercial licensing, meanwhile, is a lengthy list of bands that also are tied up in existing fixed and mobile service licences, leaving little room to introduce newer generations or competitive new market entrants. The bands reserved for unlicensed usage, meanwhile, may not be sufficient to accommodate the number and variety of uses, even as newer generations of RLANs are poised to feature larger channelization requirements and expanded capacity.

Spectrum managers might be able to handle the growing spectrum constraints in their own, measured fashion if it were not for the crisis calls of the wireless industry for additional access to mobile service spectrum for IMT networks and RLANs.[4] This is clearly being driven by the perceived market for broadband transmission of multimedia content. No operator wants to lack sufficient spectrum or have its network perceived as being incapable of providing sufficient bandwidth. And this market imperative is nearly always joined by government policy mandates to build out ubiquitous and affordable broadband networks. Indeed, wireless access is often a key element of both operators' and policy-makers' broadband strategies.

As a result, some policy-makers and companies are looking beyond the traditional spectrum planning, allocation and licensing regimes in search of answers about how to re-purpose spectrum more rapidly. The shortcomings of each traditional model, according to this critique, can be summarized as follows:

- *Administrative Licensing* – Whether they are government departments and/or broadcasters, current licence-holders often control large amounts of spectrum over long periods of time – and often in bands with the best propagation characteristics. Critics often contend that this spectrum is under-utilized, used inefficiently and held under opaque and outdated terms and conditions. [5]

- *Flexible rights-of-use* -- Once licences are obtained, commercial licensees are commonly given exclusive spectrum rights for fairly long periods, with varying degrees of accountability for how they use that spectrum.

- *Licence-exempt* – By definition, unlicensed spectrum bands offer few statistics on numbers of users or service providers. There are increasing signs that manufacturers are eager to offer greater capacity and capability, potentially boosting the demand for spectrum for RLANs and consumer devices – with an unpredictable set of results.[6] Lurking in the background is the potential for overuse of licence-exempt bands and constrained access to sufficient spectrum.

3 The New Frontier: Gaining More Usage from "Less" Spectrum

Whether it's wine, olive oil or apple cider, every commodity has what can be called "second pressings." Once the initial pressing (or stomping or threshing) has been completed, one doesn't simply accept that the resource is drained and then walk away. Rather, the process is repeated, often multiple times, to ensure that every last ounce or gram is gleaned from the precious resource. Often, it is the ninth or tenth pressing – even with a weaker or more diluted product than the initial, "virgin" pressing – that yields enough profit to last until next year.

Spectrum managers are looking for methodologies to generate just such "second pressings" of radio-frequency spectrum. They need to find ways to generate more usage of this scarce resource, and they are under severe pressure to do so rapidly.

At the same time, however, they know that the quality and usability of such spectrum "second pressings" do not unduly degrade the quality of the "first pressings." In essence, this is the conundrum of spectrum sharing: how to allow more access for some users without causing interference to all of the others. Many regulators are justifiably cautious, therefore, in examining the options for sharing and how those approaches will affect existing rules and incumbent stakeholders.

3.1 Options for "Second Pressings"

If one looks at an allocation table (either the ITU's global allocation table, incorporated in the Radio Regulations, or a national table), there appears to be no such thing as unused spectrum. There is an allocation label on every band (and frequently more than one per band). Indeed, if spectrum were land, every inch already would be occupied. With spectrum, however, we are not speaking of concrete and steel but of signals, which can vary in terms of strength, wave form and time (i.e., pulses or changes defined by duty cycles). What spectrum monitoring equipment may detect is not necessarily a static edifice of signals, but rather a complex ballet of energy, which can vary and be influenced by power limitations, directional antennas or "bursts" of data. To simplify, even when a certain frequency is allocated and assigned, it is not always in use, or "occupied" by a transmission, 100 per cent of the time, or over 100 per cent of the territory.

Again, employing a perhaps over-simplified model, spectrum usage can be envisioned in three dimensions:

(1) Frequency
(2) Time
(3) Physical space/geography

In other words, spectrum use can be perceived as cubic or "three-dimensional," and the empty lapses or "white spaces" left open in these three dimensions are opportunities for **sharing** among different uses, whether they are completely different radiocommunication services or just different transmissions within the same service. These opportunities for sharing are briefly explored in the following sub-sections.

It is important to note, however, that the "cube" concept only goes so far in explaining the concepts behind sharing. It does not take into account the ways energy is radiated, including power levels, how receivers can vary in sensitivity, differences in wave forms, etc. These elements of physics and radio engineering are pivotal in understanding how to boost equipment performance and prevent interference. A comprehensive overview of sharing methods can be found in Report ITU-R SM.1132 "General principles and methods for sharing between radiocommunication services or between radio stations."

3.1.2 Frequency-based sharing

Within any licensed block of spectrum, there are multiple frequencies that are commonly grouped together as *channels*, and spectrum-dependent systems commonly are designed to be tuned across multiple channels. Regulators can consolidate or "re-pack" existing channels, and such re-channelization can result in greater access to channels by new operators. Depending on factors such as the power levels employed by transmitters, the ability to boost signals by directional antennas, and other technical variables, even different services could share a previously monolithic spectrum block – perhaps with retention of a "guard band" to act as insulation between the two different services. Some types of services need to have separate channels for downlinks and uplinks (satellites and cellular mobile services, for example), and these channels can be alternated or "interleaved" with channels assigned to other services or operators.

Technological advances constitute a double-edged sword for frequency sharing in this manner. On the positive side, more efficient equipment, including advanced antenna systems, can achieve equal throughput using smaller channels, allowing a process known as "narrow-banding."[7] This constitutes essentially re-farming current operators on the same spectrum, but on narrower channels (e.g., downshifting from a 25 kHz channel to a 12.5 kHz channel). On the other hand, the growth of broadband mobile services is actually prompting expansion of channels to achieve greater capacity for data, with transmission standards calling for channels of 20 MHz or even wider.

3.1.3 Time-based sharing

Similarly, wireless transmissions occur continually – but very seldom are they continuous. The range of periods when transmissions are not taking place can range from fractions of seconds, in the case of "bursty" data or radar pulses, to long strings of hours, such as when broadcasting stations suspend programming overnight. Through pro-active coordination or regulation, technical protocols or operational agreements can allow sharing to take place through utilizing these gaps in timed transmissions or duty cycles.

3.1.4 Geographic-based sharing

Perhaps the most common – and easily achievable – form of sharing is re-use based on geographic separation. Maritime radio systems may be able to use the same frequencies as land-based transport fleets – provided that they are de-conflicted in the port areas where they may overlap. Geographic separation can be achieved purely through such differences in usage or by creating geographic exclusion zones that preclude operation of one type of wireless system in the area reserved for another.

Geographic sharing can also be facilitated by limiting the power level, range and directionality of one or more types of systems, thus precluding, or at least minimizing, the potential for interference with other operators in the same bands (or in adjacent bands). Indeed, all three dimensions of sharing are made possible through a combination of regulatory requirements (often, but not always, imposed through licensing) and technological requirements. The latter are built into equipment through standards development, certification and national-level type approvals. The technological changes in recent years that have paved the way for greater sharing are explored in more detail in Section 3.3.

Several governments already have experimented with the sharing among diverse users, at least in limited ways. The most common response has been to allow unlicensed or *class licence* operation of low-power, short-range consumer and WiFi equipment. Such short-range devices, such as those empowered with Bluetooth or WiFI capabilities, are a prime example of interference-avoidance that uses a combination of geographic separation and power levels. However, if large numbers of such devices proliferate in a given area, such as a densely populated urban zone, they can raise the overall spectrum *noise floor* to a level where the devices begin to cause interference (or capacity loss) to each other and to other services in the same or adjacent bands – the classic drawback to a spectrum "commons" approach.

So far, we have examined the evolution of basic sharing techniques that have become fairly common in their application across many countries. The following sections explore some techniques that have evolved in some countries, but are less commonly applied in many of them. Where there are drawbacks, or where results have been sub-optimal, these results will be noted.

3.1.5 Subdividing Licences – Spectrum Disaggregation and Trading

Within the realm of individually granted licences, there are also ways to achieve spectrum re-use. The simplest way is simply to establish smaller licensing areas rather than issuing a nationwide licence for each band. Some countries establish different-sized licensing areas for licenses intended for auction, allowing smaller market entrants an opportunity to gain spectrum niches in selected urban markets or in rural areas not coveted by larger carriers. For some administrations, however, the downside to this approach may be creation of non-lucrative licence areas that go unwanted as operators "cherry-pick" more densely populated or wealthy market areas.

Another way to generate re-use is to subdivide a licence geographically, allowing different operators to use the same spectrum in different locations. This is known as licence disaggregation, and it has been allowed in some countries, within some bands, for more than a decade.[8] This can be achieved by creating entirely new licences, or through spectrum leasing arrangements (which can also subdivide spectrum bands through leasing a portion or channel of a given band).

The "TUF" *(Titulo de Usufructo de Frecuencia)* pioneered in Guatemala provides an example of a tradable "property right" that allows a holder to exercise flexibility in a given band of spectrum as long as they adhere to technical criteria governing:

- Maximum transmission power;
- Coverage area;
- Maximum interference at border of coverage area; and
- Schedule of operation.[9]

Some experiments include the idea of "band managers" – entities that oversee (and take responsibility for) use of spectrum by a collection of subsidiary users. As explained in the ICT Regulation Toolkit, "A band manager will typically have assignment rights over, or be the licensee of, a block of spectrum, which it will then subdivide among many users. In many respects, a band manager can be thought of as a 'wholesaler' of spectrum, which it then 'retails' to individual users." [10]

As these descriptions indicate, spectrum "trading" can be defined to include some very different processes. One form of such trading is the transfer of a licence from one entity to another through approval of an acquisition or merger of the license-holder. In many countries, regulators must approve such transfers, which essentially give regulators a chance to determine whether, in fact, consolidation of two previously competitive market players would be in the public's interest. The other processes of trading, such as tradeable rights or disaggregation and leasing, as mentioned above, have been much more rare – and implementation has not always brought about the desired results.

Initial experimentation in spectrum trading was confined to a handful of countries: notably, Australia, New Zealand, United States, Canada, and Guatemala.[11] In this decade, the Office of Communications (Ofcom) in the United Kingdom has been active in authorizing spectrum transfers and leasing.[12] As a whole, the European Union has taken a cautious approach to spectrum trading, viewing both its potential benefits and possible draw-backs in terms of market failures from spectrum hoarding and lessening of competition.[13] Where trading rules have been approved, initial trading levels have often been disappointing, leading to questions about the utility of the concept.

The OECD has noted concerns among some countries about potential unforeseen effects of introducing spectrum trading (at least in terms of allowing leasing or transfer of discrete spectrum bands), summarizing those concerns as:

- Low spectrum trading activity
- Inefficient use of spectrum
- High transactions costs

- Risk of increased interference
- Impact of spectrum trading on anti-competitive conduct
- Impact on investment and innovation
- Impact on international co-ordination / harmonisation
- Windfall gains
- Disruptive effect on consumers
- Reduced ability to achieve public interest objectives.[14]

For most regulators, the idea of fungible licensing areas and transferring responsibility to other entities is worrisome, or even alarming. In addition to potential cherry-picking of small geographic markets, most concerning to regulators is the idea of losing direct control over licence-holders that may be able to transfer, lease out or (in practical terms) sell their licences. This loss of control may result in speculation (buying up fallow spectrum and selling it later at a profit) or commoditization of access. Leaving aside those concerns, regulators may have a simple fear of losing sight of who ultimately controls (and is responsible for) a licence. In terms of enforcement, such a loss of control could endanger the regulator's ability to safeguard and regulate the use of spectrum resources, bridge the digital divide or resolve interference cases.

Spectrum subdivision and trading, however, can be made subject to regulatory approval. And the ability to flexibly add and subtract access to spectrum in different geographic markets is, at least in theory, economically empowering. Operators can generate capital for network expansion by leasing out unused spectrum in certain areas, or they can buy up and aggregate licences in new markets as they grow. In short, spectrum disaggregation and trading implies acceptance of a kinetic spectrum environment rather than a static one. Business plans can evolve, change and grow as operators expand or retrench, using as much spectrum or as little as they need at any given stage of market penetration.

For now, however, spectrum trading remains limited in terms of global acceptance by regulators. This is based partly on core regulatory concerns about unintended outcomes, as noted above, and partly on a limited and mixed track record for outcomes of spectrum trading – even where it has been enthusiastically embraced.[15]

3.1.6 Spectrum Re-Farming

Re-farming of spectrum is the process of re-purposing a block of frequencies from an existing use, which may no longer be optimal, to another, more productive use. (Detailed analysis of methods and challenges of spectrum re-farming can be found in the Report ITU-R SM. 1603 "Spectrum redeployment as a method of national spectrum management.") Sometimes the term re-farming is applied as a synonym for relocation of an incumbent user out of a band to make way for re-assignment of that spectrum (See Box 1). For example, a non-commercial government or industrial band could be cleared of existing users and then licensed for a commercial service. That band could be said to have been re-farmed for a new use.

Re-farming does not necessarily involve clearing a band or switching spectrum rights from one user to another. Existing licence-holders may decide, or be directed to, re-farm a band from an older, less-productive technology to a newer one. This would occur, for example, when a cellular mobile operator phased out or discontinued 2G service, enabling it to use the same spectrum band to launch 3G or 4G service. In 2013, for example, T-Mobile informed its U.S. customers, via a blog post on its website, that it would be reducing the amount of spectrum dedicated to its 2G service and re-farming much of that spectrum for its newer, more advanced network services.

> "Approximately 90% of our network traffic is on our 3G and 4G bands (1700 MHz and 2100 MHz), which is leaving our 2G bands (850 MHz and 1900 MHz) underused," T-Mobile explained. "To help make best use of our 2G bands, we will be re-farming the excess 1900 MHz spectrum from EDGE technology to HSPA+. This will not eliminate 2G 1900 coverage in an area, but will free up some of that spectrum for 4G services. This reallocation will result in increased 4G capacity, smoother connections, and fewer dropped calls."[16]

Box 1: Re-Farming Cellular Spectrum in India[17]

In India, the term "re-farming" is being applied to the original GSM licences in the 900 MHz band, which are due to reach their termination points, beginning in November 2014 (for some of the licence areas or "circles," as they are known). The government's Department of Telecommunications has proposed reclaiming all or a portion (i.e., all but 2.5 MHz) of the licences in the 900 MHz spectrum, then putting the spectrum up for auction. In addition, the government also would auction spectrum in the 1800 MHz band.

The existing licensees in 900 MHz (notably, Bharti Airtel and Vodafone) are, not surprisingly, not in favor of relinquishing the spectrum or seeing it refarmed for a new auction. The existing operators, represented by the Cellular Operators Association of India, argue that reclaiming the 900 MHz spectrum would lead to higher consumer costs, particularly if operators are forced to relocate voice services to networks in the 1800 MHz band. The latter band would entail greater costs because of the relatively worse propagation characteristics compared with the lower band.

One recent example of spectrum re-farming is the re-purposing of a portion of the UHF bands in many countries to allow broadband mobile services to operate there – a process known as the "digital dividend." The transition from analog to digital television broadcasting allowed portions of the 700 MHz and 800 MHz bands to be freed up for new usage. Following spectrum allocation and identification decisions made at WRC-07 and WRC-12, a large and growing number of countries have opted for re-deployment of this frequency resource from broadcasting to mobile broadband, in order to optimize spectrum benefits for their economies and societies.

Even with the licensing techniques reviewed in this section, which have been employed over the past several years with increasing frequency, the ongoing pressure to accelerate and facilitate sharing is prompting further experimentation on sharing. As the next section discusses, there are several technological applications that provide the basis for potential sharing innovations.

3.2 Technology enablers of greater sharing and re-use

As mentioned in the previous sections, technology development is helping to make sharing more feasible in circumstances that would have been more problematic, if not impossible, in previous decades. In fact, technological innovations feature prominently in the new licensing options that are being explored. These options are somewhat blurring the lines between licensed and unlicensed approaches as they seek to enable sharing in a more dynamic manner. Among the technology developments are:

- **"Small cell" systems (micro-cells, pico-cells, femto-cells)** – Taking the short-range, low-power concept and running with it, these systems operate very small cells and advanced modulation techniques that can provide large bandwidth and excellent spectrum re-use capabilities, essentially recreating a broadband network in a confined location, but linking it to the Internet via wired or point-to-point wireless backhaul links.

- **"Smart" antenna systems** – Developments in antenna technology, including phased-array, reconfigurable directional antennas, are allowing antennas to be incorporated, along with power limits and other techniques, as tools for mitigating interference.

- **Databases** – Envisioned to be used as part of TV white-spaces operations, they rely on the location and technical profile of protected users in a spectrum band to allow dynamic avoidance of interference between these users and lower priority, unlicensed users.

- **Dynamic Frequency Selection (DFS)** – Developed for coexistence among unlicensed Radio Local Area Network (RLAN) devices and incumbents in the 5 GHz range, DFS incorporates monitoring technology that triggers RLAN transmissions to move to another frequency when sensors detect signals from protected incumbents.

- **Cognitive Radio Systems (CRS)** – Like DFS, CRS systems sense the presence of other users in the band and avoid interference with them, "intelligently" hopping to unused frequencies in the presence of other signals. Fully realized CRS systems, however, are largely in the future.

Put together, these technologies are enabling "smarter" wireless operations, sharpening the ability to transmit without causing interference and, ultimately, improving the chances for sharing with other users in the same or adjacent band.

3.2.1 Small-cell systems

A standard or "macro" wireless cell can cover a range of tens of square kilometers and thousands of handsets. Smaller cells, known as microcells, picocells and femtocells, cover much smaller areas (as small as a 10-metre radius in the case of femtocells) and allow low-power usage.[18] This also allows for spectrum re-use and minimizes potential interference. Small cells permit better cell-edge performance and provide increased capacity in high-traffic public areas. They can be used either with or without licences; they can be used to extend the networks of licensed operators within buildings or in more remote areas (at less cost).

One use of small cells, however, is for offloading data traffic from the larger macro-cells. So common is small-cell offloading in some markets that experts predict that as much as half of all data traffic in some congested areas will be offloaded in the next few years, making small cells an integral part of some 3G network topologies. [19] This is one aspect of a trend towards using different types of network technology to deploy what is known as a heterogeneous network or "het-net," which can allow for flexible deployment of cost-effective network equipment and boost the ability of an operator to handle increased capacity demands.

3.2.2 "Smart" Antenna Systems

Smart antenna systems can include switched-beam or adaptive-array antennas, and they feature advanced signal-processing capabilities to engage in *beam-forming* and *direction-of-arrival* estimation. Essentially, they improve performance and efficiency of a radio system, which pays dividends in terms of sharing or co-existence with other radios in the same or adjacent bands. One prime example of a smart antenna technology is *multiple input/multiple output* (MIMO), which offers increased throughput without having to increase power levels or bandwidth. Because of this capability, MIMO is an important component of LTE and other current mobile service technologies.

3.2.3 Databases

One way to control interference is to avoid transmitting on channels being used by other systems in the vicinity. Databases can be used to store and make available information on the channels that may be used by lower-priority radio systems at a given location without causing interference to, or suffering interference from, the higher-priority systems authorized in the band. Any unlicensed device seeking to transmit in that band could perform a "look-up" in the database to obtain information on the available channels. As long as the device transmits only on those channels – and as long as the database is sufficiently updated – the device may be able to operate without causing or receiving interference.

This use of a database is at the heart of current *TV white space* rules and experiments in sharing (see Section 3.3.3). White-space operations can be considered an experimental form of DSA, or as it sometimes is called, "opportunistic sharing" – the practice of using, on a non-interference and non-protection basis, the gaps in transmissions by licensed incumbents. In this case, broadcast stations are generally at fixed locations, with prescribed and well-known technical parameters for transmission. In the case of wireless microphones, these can be localized based on registration of major events (i.e., concerts or festivals) and inputted into the databases, as well. This provides a generally static and relatively stable spectral environment that can be documented in the database. In some limited-time events, however, programme-making and special events (PMSE) management may be required.

3.2.4 Dynamic Frequency Selection (DFS)

Adopted for use by unlicensed devices in several sub-bands of the 5 GHz range (the 5150-5350 MHz and 5470-5725 MHz bands), dynamic frequency selection (DFS) is designed to protect incumbents in those bands from interference. The unlicensed Wi-Fi devices operating in this band are required to be equipped with DFS capability, which can monitor and detect its local spectrum operating environment. If it detects any signals from the licensed systems it is required to protect, the unlicensed device will cease transmitting on that frequency. It can then switch to another frequency (if that one is not being used) and continue operating without causing interference.

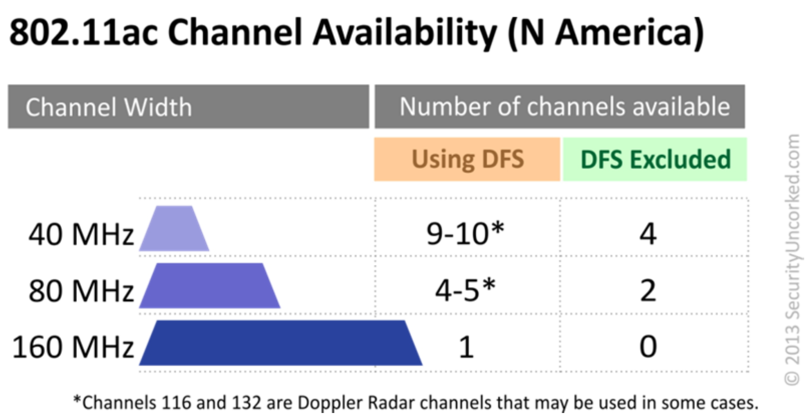
DFS featured prominently in discussions of authorizing wireless radio local area networks (RLANs), in the 5 GHz bands during WRC-03. Supporters of allowing Wi-Fi operations in those bands advocated DFS as a regulatory protection for incumbents, which included operators of radars and other equipment with sensitive reception characteristics.

DFS was controversial then, and it has not turned out to be a panacea in the decade since WRC-03. In some cases, RLAN devices that were supposed to be equipped with DFS capabilities have failed to turn off, causing interference to radars.[20] In other cases, devices designed to operate in multiple unlicensed frequencies were deployed in the bands where DFS is required, but those devices did not have functioning DFS capabilities – which also led to interference. Because the RLAN devices are not subject to licences, it is not practical to locate or account for all of them, so enforcement becomes difficult if operators use equipment not designed for this band (i.e., without functioning DFS capabilities, or if these capabilities deliberately are disabled by the operator).

Moreover, the necessity of employing DFS-equipped gear in the relevant bands appears to have prompted some avoidance of these bands by some industry segments – the exception being the enterprise market. Commercially available networking devices are increasingly shipping with DFS capabilities, as embodied in the 802.11h standard.[21] However, the use and growth of DFS is being driven almost entirely by enterprise products and users. Only a small fraction of consumer devices (home routers and mobile access) are DFS-capable, while the majority of enterprise access points are.[22]

When Wi-Fi channels were relatively narrower, it was easier to operate in bands where DFS was not required. However, newer standards, such as IEEE 802.11ac, are optimized to function with much wider channels (i.e., 80 MHz or even broader). As bandwidth grows, the number of channels that can be employed without the DFS requirement may be shrinking accordingly (See Figure 3).[23]

Figure 3: Wi-Fi: As Channels Get Wider, DFS Becomes Unavoidable



Source: Information Week: Network Computing[24]

3.2.5 Dynamic Spectrum Access

The use of databases and DFS techniques can be seen as building blocks toward the goal of allowing sharing on nearly a real-time, fluid basis. Sensing techniques like DFS can be employed to detect the presence of transmissions from another radio and avoid interference. If a radio is able to dynamically shift its use from one frequency to another within a certain frequency range, this can be combined with sensing techniques to enable what can almost be called an "intelligent" – or, as the actual term states, "cognitive" – radio system that will transmit only on unused frequencies

However, if a specific band is congested, situations may occur when there are no more available frequencies to "jump" to for operation of a DSA application. In these cases the lower-priority device it has to switch off and stop providing services to its subscribers. This uncertainty represents a significant limitation to investments.

Cognitive radios have been in development for many years, along with so-called *software-defined radios,* which can be re-programmed to transmit across a broad range of frequencies, with changing power and modulation schemes but without sensing capability. The concept of a fully developed cognitive radio system, however, is still facing lingering obstacles. Foremost among these is the need to communicate within a network. It is not enough for a single radio to sense a potential interferer and hop to another frequency. It must communicate to all other receivers in its network that it is now using another frequency, and what that new frequency is. Those other receivers must notify all other devices to which they are linked, in a cascading fashion. In other words, the entire *network* must be cognitive, and it must shift rapidly and efficiently from one channel to another without losing connection or dropping transmissions. This is clearly a complex engineering task -- one that industry has not yet resolved (See Box 2).

This complexity is further increased by a need to create reliable sensing systems for cognitive radios. For technical reasons, such as hidden obstacles and requirements for very sensitive and expensive receivers, sensing may be not fully reliable to avoid interference. Other sources of information for obtaining knowledge about electromagnetic environment are then necessary.

Meanwhile, the regulatory aspects of dynamic spectrum access are also being discussed and explored, with many implications yet unclear. Is it possible or advisable for DSA to be implemented outside bands particularly set-aside for it? How would it affect different types of radiocommunication services – particularly those with sensitive receivers? How can incumbent users be assured of their primary rights to access spectrum? What will it mean to have global allocations and national licences, if equipment can hop into and out of spectrum bands independently? When (or if) dynamic spectrum access becomes a reality, how can regulators ensure that it will not be abused? How would current licensing models be adapted?

The next section of this paper begins to explore these questions, starting with the last one – regarding adaptation of licensing. For here is where some policy-makers are, themselves, beginning to examine new options and hybrids that may pave the way for more dynamic spectrum usage. The gateway to this experimentation is, as this paper stated out the outset, the need to facilitate spectrum sharing.

Box 2: Efforts to Realize Cognitive Radio System Development[25]

ITU-R's Working Party 5A had a workshop on CRS and white spaces in November 2013. A key point that emerged was that some CRS features currently exist, or are in meaningful development. SPECTRA, a research project in Europe that ran from 2010-2014, successfully developed CRS system protocols and a supporting hardware system, which had a field trial April 23-24 2014. Technical specifications are currently being developed for civilian/commercial use of CRS. *Slides of all the presentations can be found at http://www.itu.int/oth/R0A06000059/en.*

In addition, a 2012 meeting of the South Asian Telecommunications Regulators' Council produced a report on CRS, which had several key findings about the current and future state of the technology:

- "Full Cognitive Radios do not exist at the moment and are not likely to emerge until 2030, when fully flexible SDR technologies and the intelligence required to exploit them cognitively can be practically implemented. We expect basic intelligent reconfigurable CR prototypes to emerge within the next five years. Some devices available already have some elements of CR. Examples include adaptive allocation of frequency channels in DECT wireless telephones, adaptive power control in cellular networks and multiple input multiple output (MIMO) techniques." And indeed, those prototypes have emerged (see above SPECTRA example).

- Current regulatory models are insufficient to properly accommodate CRS technologies; this is in large part because the CRS algorithms would have to be visible to regulators in order to allow them to make intelligent decisions (rather than using power level or frequency constraints as a blunt instrument). This difference between CRS and current "dumb" systems would necessitate a fundamental paradigm shift in regulatory models, as well as a level of transparency from vendors and telcos that may not be readily forthcoming.

➢ Technical issue 1: Traditional radios have filters on them to screen out interference before signals are collected and passed along for processing. CRs can't have such a filter, because they need to be able to sense all relevant frequencies, even those that are not actually operating at a particular time. This increases the potential for interference. In addition, interference-screening circuits and software in traditional radios use the radio's frequency and bandwidth settings in their calculations; without those numbers (which are not available for a CR until AFTER such calculations are performed), the calculations are considerably more complex, which again raises the potential for inadequate interference screening.

➢ Technical issue 2: The processing power and memory required for a CR unit is much higher than that of a traditional radio, making hardware design and construction more difficult. In addition, the aggregate complexity of an entire system of CRs is much higher than that of traditional radio systems, requiring a more challenging, complicated, and exacting design process for the back-end architecture or the system, and the central control component, in terms of both hardware and software.

3.3 Licensing Innovations to enable greater sharing

With the goal of enabling more – and more efficient – usage of spectrum, regulators have begun to reassess their regulatory tools and embark upon new forms of licensing (including combinations of licensing and unlicensed usage). This is a complicated task, because industry stakeholders invariably wish to preserve or enhance approaches that work for them. For example, licensed operators are extremely reluctant to give up their rights to exclusive use of a set band in a set geographic area, because of the often high price paid to access that spectrum and the ensuing substantial capital outlay for network deployment. Meanwhile, manufacturers of RLAN equipment seek more avenues to develop unlicensed bands that will accommodate a profusion of RLAN uses. The following subsections explore the ways in which previously distinct licensing modes have started to blur.

3.3.1 Operator offloading onto unlicensed spectrum

There are multiple modes for initiating small-cell data offloading. One mode involves the user deciding to initiate the offloading data onto an unlicensed (often Wi-Fi) network with their own smart phones, most of which now come equipped with WiFi capability. Another mode allows the cellular operator to detect impending network congestion and initiate the data traffic offloading, which could be to small cells (e.g., femtocells) or even directly to the Internet through WiFi. This latter, remotely initiated offloading is sometimes known as operator-managed offloading. From a licensing perspective, it is an interesting, if niche-oriented, example of the interplay between licensed and unlicensed networks. In the end, however, it may represent only a short-term solution for users and operators in highly congested areas and markets until more IMT spectrum can be mobilized.

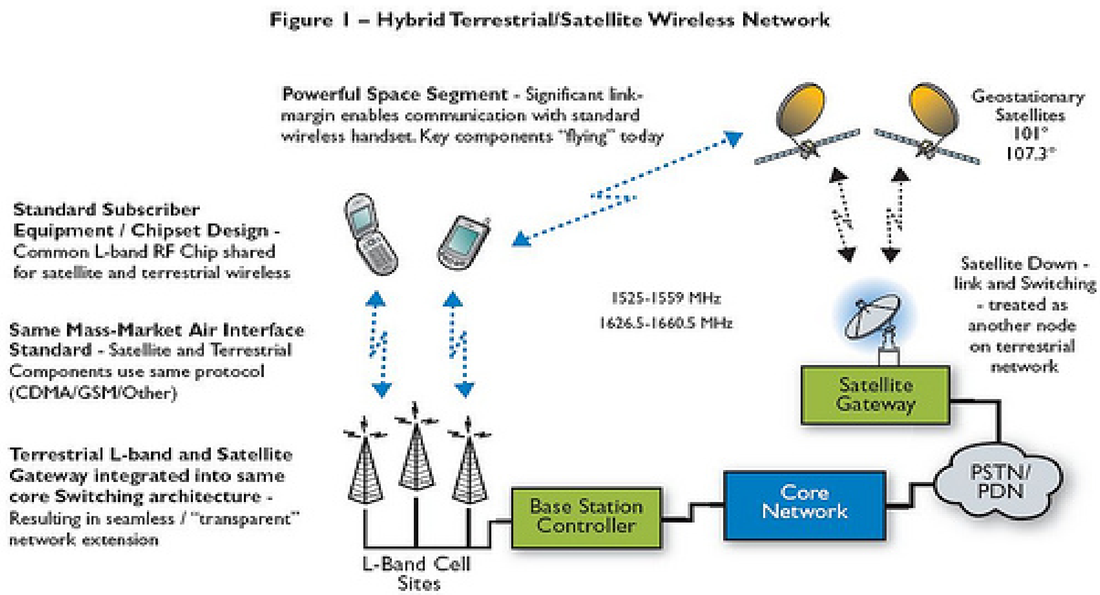
On the last day of March, 2014, the Federal Communications Commission in the United States altered its domestic rules applying to RLAN use of the 5150-5250 MHz band. Among other things, the FCC reduced the previous restriction on indoor-only use of RLAN devices and increased the permissible power, while requiring manufacturers to implement more stringent protections against illegal modifications that could cause interference to other services in the band (chiefly, the Globalstar mobile satellite system).[26] One of the benefits intended in the action, the FCC acknowledged, was to help facilitate wireless “off-loading” of traffic from cellular networks onto unlicensed transmission facilities.

This is an example of how, in at least one economy, pressure is growing to allow greater use of spectrum for unlicensed services. The 5350-5470 MHz band, which is not now authorized for RLAN use, has been proposed for RLAN expansion at the 2015 World Radiocommunication Conference. This would allow RLAN use of a contiguous range of spectrum from 5150 MHz up to 5850 MHz. Notably, however, RLANs would have to share that spectrum with incumbent satellite and radar users, complying with an array of interference mitigation techniques, including DFS and, potentially, database technologies.

3.3.2 Satellite “ancillary” terrestrial spectrum

During the 2000s, mobile satellite service (MSS) providers began to request that regulators allow them to use their licensed satellite spectrum to facilitate terrestrial operations – essentially, to use satellite spectrum for ground-based services in the L-band (1525 – 1559 MHz and 1626.5 – 1660.5 MHz). The MSS operators couched those operations in terms of support for their primary satellite services, dubbing them an "ancillary terrestrial component" (ATC) that was necessary to fill coverage gaps and provide a more reliable service. In the United States, the FCC agreed – with conditions – and paved the way for what could be viewed as a hybrid satellite/terrestrial network topology using spectrum allocated and licensed to MSS providers.[27] The Commission termed this an "integrated" MSS service with a terrestrial component.

Figure 4: Example Configuration of a Hybrid Satellite/Terrestrial Network (SkyTerra)[28]



Source: http://www.dailywireless.org/2009/08/24/motorola-skyterra-team-for-700-mhzsat-radios/

Opponents of the ATC approach were concerned that it would allow satellite providers to gain a "back-door" entry into the cellular mobile wireless market, but the FCC determined that the ATC operations would not be a functional substitute for licensed mobile service. Thus, the ATC would not enable direct competition with cellular mobile. However, the Commission did establish "gating criteria" – essentially, conditions that the satellite companies would have to prove before being granted ATC authority. MSS operators were then required to apply for permission to operate an ATC component, based on a showing that they met the gating criteria. Essentially, the FCC created a conditional licence extension, across two radiocommunication services, but with case-by-case approval required.[29]

Leasing of MSS(/ATC) spectrum was not allowed until 2011, when FCC changed the rules to allow it. Currently, holders of licences for MSS+ATC services can lease those rights to others, but only in "spectrum manager" arrangements, in which the original licensee takes responsibility for ensuring that the secondary user complies with all the relevant regulations and licence terms. In addition, the secondary user must continue to use the spectrum under the existing rules, meaning that it must be used for an MSS/ATC integrated network function. Subject to these restrictions, MSS-ATC license-holders can lease their spectrum in any geographic or band division they choose. The license-holders must notify the FCC of any leasing arrangement they intend to enter, but unless a public policy issue is raised, approval will be processed immediately.[30]

In the case of WiFi offloading discussed in the previous section, we saw a blurring between licensed and unlicensed regulation of spectrum usage. With ATC and similar hybrid licences, the lines between allocations to previously separate services are being blurred. With ATC (just as with WiFi offloading) the innovation allows regulators retain their licensing authority, to monitor and enforce the operators' behaviour. But the operators gain greater flexibility to use spectrum to meet their broad operational requirements.

However, the advent of MSS/ATC has been clouded by uncertainty. SkyTerra, which was the initial company to apply for and receive ATC authority, was subsequently acquired by Lightsquared, which has run into opposition to its terrestrial broadband network plans due to concerns about potential interference to Global Positioning System (GPS) operations.[31]

We now transition to exploring an approach to spectrum authorizations that draws directly from the ability to utilize database technologies for sharing.

3.3.3 TV white spaces

TV whites space (TVWS) has been authorized in the United States and is the subject of field trials in the United Kingdom and in several countries in Africa (see Section 4.2.2).[32] The approach involves using databases that provide for the protection of TV services under 698 MHz, as well as other licensed services operating in these bands, such as broadcasting auxiliary services (i.e., wireless microphones). The databases can be accessed and updated via the Internet and are maintained by multiple parties on a fee basis.

One of the challenges related to databases, especially for countries with small territories, is coordination of TVWS devices in border areas. This may require exchange of information kept in national databases, since frequency usage, rules and available channels can be different in neighboring countries. Such exchanges may represent significant administrative difficulties. The databases then allow unlicensed network equipment and devices (essentially, part of radio LAN systems such as WiFi) to avoid interference to and from higher priority uses in the band.

Equipment must be designed and deployed to interact with the database and adjust its transmissions as mandated by the data-base. TVWS proponents are requesting that regulations be stabilized so that providers can be certain that the spectrum they are using, on an unlicensed basis, will not be reallocated or auctioned for licensed usage, for example, by cellular mobile providers.

With regard to building an equipment "universe" for TV white spaces, IEEE has been developing a standard for TV white spaces devices, under the rubric of 802-11af – an offshoot of the Wi-Fi suite of standards. IEEE 802.22 is another standard for Wireless Regional Area Networks (WRANs) using TV white spaces.

In terms of licensing, TV white spaces illustrate (like RLANs potentially using DFS at 5 GHz to share spectrum with radars) a combination of licensing and unlicensed strategies. The incumbent users (primarily broadcasters or wireless microphone systems) typically retain existing broadcasting licences. The licensed operators retain primary regulatory status in the band, meaning that they must be protected from harmful interference by the TV white spaces devices. The latter are used without licensing, giving them secondary status (or no status) in the band. That is, the white spaces devices cannot cause harmful interference to broadcasting, and they must accept interference from the broadcasting or Broadcasting Auxiliary Service (BAS) operations when that occurs. The use of the database, however, enables the TV white spaces devices to operate without either causing or receiving interference to/from the incumbent services.

As documented in a chapter of ITU *Trends in Telecommunication Reform*'s 2013/14 special edition, TV white spaces remain nascent in most parts of the world – and uncertain even where they are operating: in the United States, early advocacy of TVWS in television broadcasting bands has been superseded by an effort to design incentive auctions (See Box 3) that would provide for licences for broadband wireless (while re-farming broadcasters into a smaller spectrum range). It is not yet clear how much spectrum will remain for TVWS usage.

Box 3: The FCC's Broadcasting Incentive Auctions[33]

The U.S. Federal Communications Commission (FCC) has designed an "incentive auction" process to provide market incentives for local television broadcasting stations to release some of their spectrum to be auctioned for broadband mobile services.

The process will involve two "separate but interdependent" proceedings:

- a "reverse auction," in which the broadcasters "bid" the prices at which they would be willing to give up their spectrum, and
- a more familiar "forward auction," in which the mobile providers submit bids for how much they would be willing to pay to acquire it.

The FCC will take both sets of bids, "repack" the entire spectrum range such that the broadcasters who will remain after the auction (those who chose not to participate, or whose sell prices were not met) are located together on the spectrum, and issue the remaining "sold" spectrum to the mobile providers with winning bids.

In other words, the FCC is taking what would be a two-step buyback-and-resell process and making it into a simultaneous auction, in order to allow repacking, and also use information from each auction in the other auction, to allow a closer alignment of buying and selling points. All broadcasters will be affected by this auction proceeding, whether or not they choose to sell, because of the probability that their channel will be changed by the repacking.

3.3.4 Licensed Shared Access

While the unlicensed use of TV white spaces amounts to "swimming at your own risk," it can provide a means for exploiting unused spectrum that would otherwise remain fallow. It does not appeal, however, to cellular mobile operators – at least not as a spectrum strategy for their core voice networks. These operators overwhelmingly prefer to retain their licensed occupation of assigned bands, which the operators have often "paid for" in terms of gaining exclusive rights through auction or tender processes. The operators essentially have paid for the right not to endure the vagaries of database look-ups, saturation of spectrum capacity (often in vital urban areas) – in short, all the potential downsides of unlicensed use.

The problem is that, in an increasing number of countries, the availability of sufficient spectrum that can be cleared, re-farmed and made available for new licences is fast approaching nil. Meanwhile, there remain large ranges and bands of command-and-control assignments still being used by government departments and agencies, including for public safety, utility or asset management and military defence. What is needed is a regulatory paradigm that could meet multiple needs for spectrum access through shared use, governed by a careful balancing-of-rights management. One proposal to achieve this is *licensed shared access (LSA)*.

Box 4: Defining Licensed Shared Access[34] [35]

The GSM Association (GSMA) defines LSA in the following way:

"…an individual-license regime of a limited number of mobile network operator (MNO) licensees in a frequency band that is identified for IMT, and which is already assigned to other incumbent users whose spectrum rights of use have not been granted through an award procedure for commercial use, for which the additional users are allowed to use the spectrum (or part of the spectrum) in accordance with sharing rules included in the rights of use of spectrum granted to the licensees."[1]

The European Commission's Radio Spectrum Policy Group (RSPG) has a similar but nuanced definition, which incorporates a clause pertaining to quality of service (QoS). For RSPG, LSA is:

"A regulatory approach aiming to facilitate the introduction of radiocommunication systems operated by a limited number of licensees under an individual licensing regime in a frequency band already assigned or expected to be assigned to one or more incumbent users. Under the Licensed Shared Access (LSA) approach, the additional users are authorised to use the spectrum (or part of the spectrum) in accordance with sharing rules included in their rights of use of spectrum, thereby allowing all the authorized users, including incumbents, to provide a certain Quality of Service (QoS)."[1]

Based on the existing definitions, components of LSA appear to include the following, at a minimum:

- An LSA band would allow continued use by incumbent users, including government users;
- Cellular mobile operators would be able to enter the band, with licences that would be conditioned by technical and regulatory criteria that would allow sharing with the incumbents;
- The terms and conditions for sharing should be implemented by national regulators after consultation (or negotiation) among incumbents and new operator licensees;
- The sharing terms and conditions should allow for all parties to meet standards for QoS or, at a minimum, effective delivery of their services or completion of their missions; and
- LSA should be employed as a complement to, not a replacement for, exclusive allocations and assignments to operators in most bands.

Some descriptions of this concept user the slightly older term, *authorized shared access (ASA)*, and some include provisions for a sensing function, as with DFS or cognitive radio, to allow the non-incumbents to operate. As the LSA/ASA concept evolves, it already is being applied or considered in several regions where re-farming of government spectrum appears to be difficul. These bands and regions are:

- The 2.3 GHz band in Europe, and
- The 3.55-3.65 GHz band in the United States.

3.3.4.1 LSA in the 2.3 GHz band in Europe

In its opinion on LSA, issued in late 2013, the European Commission's Radio Spectrum Policy Group (RSPG) noted a prevailing opinion in Europe that the first practical application of the concept could involve the 2.3 GHz band in 2014.[36] The band (i.e., 2300-2400 MHz) was identified for IMT use at the 2007 World Radiocommunication Conference. However, the presence of other, incumbent users in the band delayed plans by the European Conference of Posts and Telecommunications Administrations (CEPT) to harmonise IMT use across Europe.[37] ETSI called for compatibility studies to determine whether broadband IMT (TDD IMT/WiMAX) could co-exist with the incumbents in the band under a scenario in which there would be five 20-MHz channels.[38] Those studies would include co-channel compatibility, compatibility with incumbents in adjacent bands, and cross-border compatibility.

Studies indicated a mix of compatibility and incompatibility across different countries, ranging from no issues in countries where the band was unused, up to certain countries with government uses, where compatibility might be possible on a shared basis with provisions for protection from interference. The CEPT Electronic Communications Committee (ECC) then sought to develop a decision on harmonized provisions, including LSA procedures, for those situations. That decision was due by mid-2014.[39] In short, countries without problematic issues concerning incumbents might simply allow exclusive-use licensing; where incumbents existed, administrations could implement the harmonized provisions that would include LSA.

3.3.4.2 LSA in the 3.55-3.65 GHz band in the United States

In December 2012, FCC proposed introducing a new "Citizens Broadband Service" in the 3550-3650 MHz band, as a way to allow sharing by small-cell operators without having to re-farm or clear incumbents from the band.[40] An earlier review of 3550-3650 MHz had determined that the only way to share the band otherwise would have been to create large coastal exclusion zones to protect incumbent maritime radars.[41] The required size of those exclusion zones would have made it uneconomic to deploy standard, macro-cell services in the band.

In April 2014, FCC further elaborated on its proposals, developing a three-tiered hierarchy of access to the 3550-3650 MHz band that might be described in terms of LSA.[42] Existing government users and other incumbents would continue to be protected, while the Commission proposed creating a "priority access licence" or PAL that would be offered based on U.S. census tracts. Where more than one applicant existed for a PAL, the licence could be auctioned. Each 10-MHz PAL would be good for only one year, although holders could aggregate extensions of up to five years through spectrum trading. Finally, a general access category would be created in a reserved portion of the band for users who could claim no interference protection. Database technology would be utilized to ensure that lower-priority users did not interfere with PAL holders or the protected incumbents.[43]

The so-called Citizens Broadband Service was not developed overnight, and it still faces an array of doubts: incumbent users within the Federal government have spent years studying and debating with the FCC the potential for sharing this band. Industry observers also question the PALs' auction viability, given their extremely small size and their short duration. The 3.5 GHz experiment will face two core questions: can it foster growth in this band for the small-cell market it hopes to address, and can it really combine auctioned licences shared with government incumbents *and* opportunistic users? At this juncture, it is too soon to say.

4 International and National developments

Given the current experimentation process with dynamic spectrum licensing and sharing trends, what avenues exist for broader implementation and adaptation? Beginning with TV white spaces, there are both international and national-level efforts to define and codify regulatory guidance and rules (respectively) for this new approach. It is by no means certain that dynamic sharing will work in all cases – much less become the dominant spectrum management technique that some hope it will be. It might only be applied in carefully studied parts of the spectrum, if any other than TV-white spaces are found appropriate on a case-by-case basis.

This section looks at these efforts, beginning with ITU-R developments related to these concepts, and then focusing on experiments, trials and implementation by national regulatory authorities, particularly in developing economies.

4.1 International-Level Developments

WRC-12 addressed the need to review the ITU Radio Regulations (RR) to accommodate new technologies like cognitive radio systems (CRS), but it concluded that no changes to the RR were needed for this purpose. In addition, WRC-12 recognized that while CRS systems are expected to provide flexibility and improved efficiency to overall spectrum use, radio systems implementing CRS technology need to operate in accordance with the RR provisions. Moreover, the use of CRS does not exempt administrations from their obligations with regard to protecting the stations of other administrations that also are operating in accordance with the RR.

The work of the ITU's Radiocommunication sector (ITU-R) on this issue has since continued to be focused on the development of best practices. For this purpose, the relevant study groups and working parties of ITU-R are exploring technical and spectrum management issues. For example, Study Group 5's Working Party 5A[44] has developed a preliminary draft new report on cognitive radio systems, which seeks to define the technical aspects and discuss the applications in the land mobile service that will be made possible once the technology matures and becomes more widely available.[45] This report, which is still pending in WP5A, follows other ITU-R reports and recommendations, including Report ITU-R M.2225, adopted in 2011, which provided an initial introduction to cognitive radio technologies (in the land mobile service).[46] In addition, the same working party held a workshop in conjunction with its November 2013 meeting, bringing together experts to provide a technical update on topics related to dynamic spectrum access.[47]

Box 5: ITU-R Study Group 5's Estimates of Spectrum Requirements[48 49]

At its meeting in early December 2013, the ITU-R's Study Group 5, which studies terrestrial mobile services (among others), adopted a report on mobile spectrum requirements. According to the report, which had been given initial approval by the study group's Working Party 5D, there was an urgent need to earmark spectrum for mobile cellular services[1] around the world – from 1,340 MHz to 1,960 MHz in any given area, depending on the rate of service growth and the density of market penetration in that country.[1] Moreover, this continent-sized spectrum acreage would need to be found within the bands below 6 GHz.[1]

Any operator of any spectrum-dependent system or device other than IMT or RLANs in this prime spectrum real estate now had to be on notice – if they were not already – that their ongoing access to spectrum resources was now on shaky ground.

The report did not go unchallenged at the meeting. The European Broadcasting Union (EBU) questioned its assumptions, questioned its methodology and, ultimately, sought its rejection by the Study Group. The voice of EBU, a sector member at the ITU, was not supported however, and the requirements will be considered further at the Conference Preparatory Meeting in April 2015as a reference for allocations and identification of frequencies for IMT and RLANs– to be addressed by the 2015 World Radiocommunication Conference in November of next year.

While the working parties of SG5 explore technical aspects of TV white space and cognitive radio in the land mobile service, another working party, 1B, is studying new potential spectrum management principles or approaches and developing best practices in this regard. At its recent meeting, in January 2014, WP1B agreed to establish a Correspondence Group to assist in developing a preliminary draft new Report ITU-R SM.[DYNAMIC ACCESS] on spectrum management principles and engineering techniques for dynamic access to spectrum by radio systems employing cognitive capabilities.

These studies in the ITU-R build on existing Recommendations and Reports that document technology developments, such as software-defined radios, but also well-established spectrum management principles, which are recognized and implemented worldwide and which have proven their ability to accommodate new technologies for decades. These studies, which are ongoing, benefit from the participation of all stakeholders. They particularly take into account the concerns expressed by stakeholders whose services essentially rely on international coordination and cooperation (and who provide benefits to entire international community), such as meteorological, satellite, aeronautical, radionavigation, and Earth observation services.

Many facets of DSA remain unclear, including the following technical and operational issues:

- Required protection of ubiquitously deployed satellite Earth stations that are authorized but not recorded in central databases;

- Difficulty in detecting very-low-power satellite transmissions and implementing systems able to sense such satellite transmissions;

- Protection of aeronautical safety services, which are critical to the safe operation of aircraft, since even minimal levels of interference can put at risk the safety of operational aircraft; and

- Protection of other space services (space-to-Earth) and passive services (radio astronomy, Earth exploration-satellite service and space research service) as well as radiodetermination services.

The need to protect incumbents is an issue not only for sharing in a single band or a given location, but also in adjacent bands or far away from that location.

4.2 National-Level Developments

It may be clear at this point that much of the experimentation in sharing/DSA and new licensing approaches is occurring in the more developed countries with established reputations for exploring unorthodox regulatory options. There are some pioneering efforts taking place, however, in the form of trials (particularly of TV white spaces systems) in developing countries. Some of these experiences are summarized in this section.

4.2.1 TV White Spaces Trial in Kenya

In December 2012, the Communications Commission of Kenya received an application for permission to deploy a trial TV white space network in the country. The Commission responded in August 2013, granting a one-year permit to provide TVWS at two designated rural locations, with three conditions:

- The operators obtain a Network Facilities Providers' Licence at least at a Tier 3 level – or partner with an existing licensee;
- That the applicants operate in the 470-694 MHz band only on a non-interference, non-protected and non-exclusive basis; and
- All equipment had to be type-approved by the Commission before installation and deployment.

The operators were required to deliver a report to the Commission on the performance of the system and its compliance with all conditions. The Commission reviewed the report and decided not to grant, at the present time, an operational licence. This followed some mixed trial results related to the quality of service provided.[50] The Commission described its approach as a cautious one, given the importance of the ongoing broadcasting services.

Box 6: Additional TV White Spaces Initiatives in Developing Countries[51]

Several additional trials and deployments of TV white spaces networks are occurring in developing countries, many of them as part of public-private partnerships or collaborations (see also Section 4.2.2). Some of these are summarized below:

- In the **Philippines**, a partnership involving the government, USAID and Microsoft has developed the ECOFISH project, which uses TVWS technology to deliver broadband Internet access, along with specialized government services and applications, to fishermen in several communities in the island province of Bohol. This will help attain a goal of the government to provide Internet access throughout the country by 2015.
- In May 2013, another pilot project was announced, this time in Dar es Salaam, **Tanzania**. Microsoft partners with the Tanzanian Commission for Science and Technology (COSTECH) and local Internet service provider UhuruOne, utilizing TV white spaces to offer affordable wireless broadband to university students and faculty. The pilot's initial deployment will target the University of Dar es Salaam, among others.
- **Singapore –** the White Spaces Pilot Group (SWSPG) was established in April 2012 with support from Infocomm Development Authority (IDA). The objective of the group is to deploy White Spaces technology pilots in Singapore, thereby accelerating the adoption of White Spaces technologies globally. SWSPG aims to attract broad members from public and private sectors, local and international industry, academic and research institutes and end-user organizations that could benefit from this next generation broadband wireless connectivity.

4.2.2 TV White Space Trial in Cape Town

The Independent Communications Authority of South Africa (ICASA) supported a TVWS trial in Cape Town during six months in 2013. The trial was carried out by a consortium of partners that included Google and the Tertiary Education and Research Network of South Africa (known as TENET), as well as the E-schools Network, the Wireless Access Providers' Association (WAPA) and CSIR Meraka Institute. Multiple base stations were installed at Stellenbosch University's Faculty of Medicine and Health Sciences in Tygerberg, delivering broadband network access to ten schools within a 10-kilometer radius. Although the trial officially ended on 25 September 2013, Meraka recommended to ICASA that the service to the schools be continued.[52]

Testing showed that even during peak periods, average download throughput was above 2 Mbit/s, and off-peak downloads averaged in excess of 10 Mbit/s. Upload speeds during most of the trial varied within a range of just under 2.5 Mbit/s and just over 4 Mbit/s.[53] Moreover, the trial system operated without causing any detected or reported interference to TV receivers in the area.

The concluding report indicated that TVWS could co-exist and share spectrum with broadcasting, and that allowing it would constitute a more efficient use of spectrum. It also recommended developing multiple databases and promoting competition "to drive down costs and spur innovation."[54] More broadly, the organizers advocated promoting an internationally harmonized approach to TVWS device characteristics and certification, a regional approach to spectrum management for TVWS access and the further development of TVWS equipment standards.

4.2.3 Cognitive Radio Test-Bed and Trial in China

Meanwhile, in China, the Beijing University of Posts and Telecommunications has explored TD-LTE technology for cognitive radio systems in two bands: (1) the UHF band (698-806 MHz, and (2) the 230 MHz band. This Chinese approach includes a combination of both database technology and sensing, as a way to build reliability and preclude missed detection of incumbents. The approach involves using a database for "global" or general location of incumbent receivers, and supplementing it with a "local" implementation of cognitive sensing technology.[55] A testbed has been developed for this approach to cognitive radio in the UHF band, and field trials are being prepared in Hebei and Zhejiang provinces for the 230 MHz band.

Based on its experience, the University has developed a list of policy and regulatory challenges associated with cognitive radio systems in their development stage:

- **Policy and Regulation Challenge 1 - Frequency authorization --** Possible frequency band(s) for the systems or services implementing CRS should be authorised first while accounting for existing uses in the band(s).

- **Policy and Regulation Challenge 2 - Frequency allocation --** It is hard to find harmonised dedicated frequency band(s) worldwide or even nationwide. When multiple cognitive cellular systems coexist on the same spectrum band, each of them should have equal right to access the spectrum.

- **Policy and Regulation Challenge 3 – Cross-border coordination --** Radio frequency allocation regulations are different among countries and regions. How to conclude agreement on cross-border coordination related to CRS is a big challenge.

- **Policy and Regulation Challenge 4 - Interference coordination --** To decrease interference risk, regulatory models with clear definitions of rights and responsibilities of both licensed and unlicensed spectrum users are needed.

- **Policy and Regulation Challenge 5 - Type approval --** For reconfigurable devices, the ability to alter operational frequency and transmission modes calls for a new method for type approval.[56]

4.2.4 Additional considerations

It should be emphasized that TVWS and CRS are still new concepts and they remain under study in ITU , in several countries and at a regional level as well. Some trials show a possible use of devices with CRS technology, but only under certain conditions -- in particular a need to operate with a geo-location database. Sensing techniques alone are not sufficient at this juncture.

Moreover, standards for TVWS are under development by organizations such as ETSI and IEEE. Other technical questions relate to spectrum management issues, and even those countries that have already established some national spectrum management regulations covering DSA and related approaches have indicated that these are not definitive and may evolve, taking into account new experiences.

Another area for further work is at the bilateral and multi-lateral level among countries where cross-border issues may arise. Some general principles could already be identified but no detailed answers are yet available. Other issues, which are not related specifically to spectrum management, are about the quality of service and about the comparison between TVWS and other approaches that could provide the same service to the rural areas. These issues need to be discussed at the national level, looking at medium-term and/or long-term perspectives – for example, what would be the most efficient way to bridge the digital divide. In addition the practical aspects of the type-approval process and real-time responses to possible cases of interference (e.g. enforcement) need also to be addressed carefully.

5 Conclusion

For the last ten years (since DFS was introduced), a new paradigm in spectrum management has been gaining momentum. It consists of considering spectrum access as dynamic, rather than static. Taken to its ultimate vision, this new paradigm imagines a dynamic environment in which devices and networks flexibly adapt to constraints in spectrum access with agility and mobility, much the way passengers negotiate a crowded train station or vehicles form lanes on a highway. As with those examples, there would be a set of rules and rights, often built in as software "policy" within the networks and devices themselves. Or, licensing and equipment certification would set the rules, along with coordination and negotiation among classes of users.

The previously identifiable models of spectrum distribution are now evolving into hybrids that respond to the economic needs of telecommunication operators, equipment manufacturers and users. At the same time, these hybrids often retain the administrative and public policy hand-holds that regulators and government users need to fulfill their missions. Meanwhile, new ways of expanding spectrum access are being enabled by developing technologies or licensing approaches intended to ensure coexistence with incumbent spectrum users.

It is important not to lose sight, however, of the fact that core spectrum licensing techniques still function well in a majority of economies and spectrum bands. Regulators need not abandon proven approaches that have worked for their stakeholders, even as they explore potential new departures or hybrids. Some of the new approaches many turn out to be less advantageous or necessary than first thought, and they are likely to evolve further as administrations try new rules and learn from each other.

There is also the potential for unforeseen consequences. Ten years ago, for example, FCC's Part 15 rules for unlicensed use of short-range devices ran smack into a US government mandate that Federal agencies engage in narrow-banding to use spectrum more efficiently. The U.S. Department of Defense shifted some radio operations onto bands that it held as assignments (but had not previously used widely), only to find that these bands were popular with manufacturers of unlicensed wireless garage-door openers. The garage-door openers, being unlicensed, had no rights to claim protection from interference by the Defense Department – but that did not prevent the manufacturers from descending on Washington to plead for relief.[57] It is a parable of how attempts to utilize new approaches to improve spectrum efficiency and sharing can, at times, collide.

For policy-makers interested in pushing ahead to pioneer options for spectrum management, the potential risks seem worth taking. And for the rest of us, they are providing options that can be applied – if and when they mature, and when and where needed. Meanwhile, it will be interesting to watch and see whether these new sharing experiments really turn out to be new frontiers in licensing, or simply the Wild West.

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[1] *White spaces* previously was known as "TV white spaces" because of the early pioneering of this sharing technique in the UHF television broadcasting bands.

[2] See Voyager Fact Sheet, NASA, http://voyager.jpl.nasa.gov/news/factsheet.html.

[3] See "Exploring the Value and Economic Valuation of Spectrum," ITU-D Regulatory and Market Environment, Broadband Series, April 2012. Available at www.itu.int/broadband.

[4] See Walls, John, "Wireless Spectrum Crisis," commentary in online version of The Washington Post, 20 March 2013, downloaded 17 April 2014 from http://www.washingtonpost.com/sf/brand-connect/wp/2013/03/20/wireless-spectrum-crisis/

[5] See Largent, Steve, "Why Wireless Needs More Spectrum," commentary in *Politico*, 6 February 2013, downloaded 17 April 2014 from http://www.politico.com/story/2013/02/wireless-spectrum-boost-fuels-growth-87272.html

[6] Theoretically, the ultimate result may be the "tragedy of the commons," a situation in which an unregulated resource is subject to overuse, without any mechanism to apportion access equally. The result is constrained access and a degraded resource for all users.

[7] As an example, from the US FCC: "On January 1, 2013, all public safety and business industrial land mobile radio systems operating in the 150-512 MHz radio bands must cease operating using 25 kHz efficiency technology, and begin operating using at least 12.5 kHz efficiency technology. This deadline is the result of an FCC effort that began almost two decades ago to ensure more efficient use of the spectrum and greater spectrum access for public safety and non-public safety users." See http://transition.fcc.gov/pshs/public-safety-spectrum/narrowbanding.html

[8] The U.S. Federal Communications Commission, for example, decided in 2000 to allow all commercial wireless service licensees to engage in partitioning and disaggregation of licenses. It defined those terms as follows: "`Partitioning' is the assignment of geographic portions of a radio license along geopolitical or other boundaries. 'Disaggregation' is the assignment of discrete portions or ''blocks'' of spectrum licensed to a geographic licensee or other qualifying entity." See Federal Register/ Vol. 65, No. 114 / Tuesday, June 13, 2000 / Rules and Regulations, downloaded 29 April 2014 from http://www.gpo.gov/fdsys/pkg/FR-2000-06-13/pdf/FR-2000-06-13.pdf

[9] ITU and infoDev, ICT Regulation Toolkit, see https://www.ictregulationtoolkit.org/en/toolkit/docs/Document/3274

[10] Ibid, Module 6, section 5.1, "What constitutes an effective regulator?"

[11] See OECD, "Secondary Markets for Spectrum: Policy Issues," Working Party on Telecommunication and Information Services Policies, Directorate for Science, Technology and Industry, DSTI/ICCP/TISP(2004)11/FINAL, 20 April 2005.

[12] See Ofcom "Trading Guidance Notes," OfW513, December 2011, downloaded from http://stakeholders.ofcom.org.uk/binaries/spectrum/spectrum-policy-area/spectrum-trading/tradingguide.pdf.

[13] Kelly, Robert B. and Ann J. LaFrance, "Spectrum Trading in the EU and the U.S. – Shifting Ends and Means," Chapter, Squire Sanders publication, 2012, downloaded 25 May 2014, http://www.squiresanders.com/files/Publication/8ce3ed01-56b5-475a-af16-969ee634df4f/Presentation/PublicationAttachment/9ff7086b-589b-4fdd-bbc6-970717b5837b/Tel12_Squire%20Sanders_ver4.pdf

[14] OECD, Secondary Markets report, p. 5.

[15] See for example, Ofcom UK, "Implementing Spectrum Trading," consultation paper, July 2002, http://www.ofcom.org.uk/static/archive/ra/topics/spectrum-strat/consult/implementingspectrumtrading.pdf

[16] T-Mobile blog post, downloaded 12 April 2014 from http://support.t-mobile.com/community/coverage/blog/2013/12/17/network-modernization-update

[17] See Mitra, Sounak, "Refarming of Spectrum May Emerge as $10 Billion Business Opportunity for Equipment Makers, Business Standard, New Delhi, 4 December 2013, http://www.business-standard.com/article/companies/refarming-of-spectrum-may-emerge-as-10-bn-business-opportunity-for-equipment-makers-113120400893_1.html. Also, see "Telecom Commission for Re-farming Entire Spectrum in 900 MHz Band, The Hindu, 17 October 2012, at http://www.thehindu.com/business/Industry/telecom-commission-for-refarming-entire-spectrum-in-900-mhz-band/article4005442.ece?css=print

[18] See "High-Capacity Indoor Wireless Solutions: Picocell or Nanocell," Fujitsu information paper, pg. 1, at http://www.fujitsu.com/downloads/TEL/fnc/whitepapers/High-Capacity-Indoor-Wireless.pdf. See also, Baines, Rupert, "The Crib Notes for Nanocells 101," OSP magazine (blog), at http://www.ospmag.com/issue/article/The-Crib-Notes-for-Nanocells-101

[19] Calabrese, Michael, "Solving the Spectrum `Crunch': Unlicensed Spectrum on a High-Fiber Diet," New America Foundation, October 2013, p. 7. Available at http://www.twcresearchprogram.com/pdf/TWC_Calabrese.pdf

[20] Tristant, Philippe, Frequency Manager of Meteo France. "RLAN 5 GHz Interference to Weather Radars in Europe," presentation to ITU/WMO Seminar on use of radio spectrum for meteorology:Weather, Water and Climate Monitoring and Prediction," 16-18 September 2009.

[21]] IEEE, available at http://standards.ieee.org/findstds/standard/802.11h-2003.html.

[22] Data from Wi-Fi Alliance, http://www.wi-fi.org/certified-products-advanced-search."

[23] See http://chimera.labs.oreilly.com/books/1234000001739/ch05.html#additional_planning_considerations, downloaded 6 May 2014.

[24] See Jabbusch, Jennifer, "Dynamic Frequency Selection Part 3: The Channel Dilemma," at http://www.networkcomputing.com/wireless-infrastructure/dynamic-frequency-selection-part-3-the-channel-dilemma/a/d-id/1234489?

[25] SATRC Working Group on Spectrum, "Challenges of Future Technologies in Spectrum Management: Cognitive Radio," Adopted by 13th Meeting of the South Asian Telecommunications Regulators' Council, 18-20 April 2012, Kathmandu, Nepal.

[26] See FCC press release, "FCC increases Availability of Spectrum for High-Speed, High-Capacity WiFi and other Unlicensed Uses in the 5 GHz Band," released March 31, 2014.

[27] See *Flexibility for Delivery of Communications by Mobile Satellite Service Providers in the 2 GHz Band, the L Band, and the 1.6/2.4 GHz Bands; Review of the Spectrum Sharing Plan Among Non-Geostationary Satellite OrbitMobile Satellite Service Systems in the 1.6/2.4 GHz Bands*, IB Docket Nos. 01-185 and 02-364, Report and Order and Notice of Proposed Rulemaking (*MSS Flexibility R&O*), FCC 03-15, 18 FCC Rcd 1962 (2003).

[28] SkyTerra was acquired by LightSquared in July 2010.

[29] According to the U.S. Federal Register, the FCC , responding to a request by Globalstar, "proposed to modify its rules for operation of the Ancillary Terrestrial Component (ATC) of the single Mobile-Satellite Service (MSS) system operating in the 2483.5-2495 MHz band [i.e., Globalstar]. The proposed rule changes would allow the MSS operator to deploy a low-power terrestrial broadband network that would operate in both Globalstar's licensed spectrum at 2483.5-2495 GHz, and, with the same equipment, spectrum in the adjacent 2473-2483.5 MHz band used by unlicensed devices."

[30] See Federal Communications Commission, Report and Order, Docket No. 10-142, "Fixed and Mobile Services in the Mobile Satellite Service Bands at 1525-1559 MHz and 1626.5-1660.5 MHz, 1610-1626.5 MHz and 2483.5-2500 MHz, and 2000-2020 MHz and 2180-2200 MHz," FCC 11-57, paragraphs 17-18.

[31] See http://en.wikipedia.org/wiki/LightSquared.

[32] See, with regard to Canada, http://www.cata.ca/Media_and_Events/Press_Releases/cata_pr05171302.html. For TVWS in the UK, see http://stakeholders.ofcom.org.uk/spectrum/tv-white-spaces/. And in the U.S., see http://www.fcc.gov/encyclopedia/white-space-database-administration-q-page

[33] Federal Communications Commission, "The Broadcast Television Spectrum Incentive Auction," FCC Staff Summary, see http://www.fcc.gov/document/broadcast-television-spectrum-incentive-auction-staff-summary

[34] GSM Association, "Licensed Shared Access and Authorised Shared Access," GSMA Public Policy Position Paper, February 2013, p. 4.

[35] European Commission, Directorate-General for Communications Networks, Content and Technology, Radio Spectrum Policy Group (RSPG), "RSPG Opinion on Licensed Shared Access," *("RSPG Opinion")* RSPG13-538, 12 November 2013, p. 7.

[36] RSPG Opinion, p. 22.

[37] CEPT provides technical guidance, planning and coordination for its European member states, including in the area of spectrum allocation and management.

[38] Espinosa, Bruno, "LSA in the 2.3-2.4 GHz Band," presentation on behalf of the European Communications Office at the Trial LSA Workshop, Helsinki, 3 September 2013, slide 4.

[39] Ibid, slide 7.

[40] *See* Amendment of the Commission's Rules with Regard to Commercial Operations in the 3550-3650 MHz Band, GN Docket No. 12-354, Notice of Proposed Rulemaking, 2012.

[41] *See* "An Assessment of the Near-Term Viability of Accommodating Wireless Broadband Systems in the 1675-1710 MHz, 1755-1780 MHz, 3500-3650 MHz, and 4200-4220 MHz, 4380-4400 MHz Bands (President's Spectrum Plan Report)," NTIA, November 2010.

[42] The FCC also has proposed adding the 3650-3700 MHz band to the allocation, amounting to 150 MHz of spectrum that could be utilized, in a managed way, for broadband sharing. See FCC press release at http://www.fcc.gov/document/fcc-proposes-make-150-mhz-spectrum-available-broadband

[43] Parker, Tammy, "Fcc's Latest Proposal for 3.5 GHz band Includes Auctioned Licences," FierceWirelessTech, 23 April 2014, downloaded 25 May, at http://www.fiercewireless.com/tech/story/fccs-latest-proposal-35-ghz-band-includes-auctioned-licenses/2014-04-23

[44] SG5 is the technical group for wireless terrestrial services. Its Working Party 5A explores land mobile services other than IMT, which is under the aegis of WP5D.

[45] See Annex 20 to Document 5A/421-E, Preliminary Draft New Report ITU-R M.[LMS.CRS2], "Cognitive Radio Systems [(CRS) applications] in the land mobile service," Annex 20 to the Working Party 5A Chairman's Report, 2 December 2013.

[46] See http://www.itu.int/pub/R-REP-M.2225

[47] See http://www.itu.int/en/ITU-R/seminars/rsg/RWP5A-2013/Pages/default.aspx

[48] The report addressed requirements for overall spectrum amounts required for International Mobile Telecommunications or IMT, including existing and future, IMT-Advanced, networks.

[49] See Report ITU-R M.2290-0, "Future Spectrum Requirements Estimate for Terrestrial IMT," December 2013, page 14.

[50] Haji, Mohamed A., Communications Commission of Kenya, "Licensing of TV White Space Networks in Kenya," presentation to ITU-R WP1B workshop on Spectrum Management Issues on the Use of White Spaces by Cognitive Radio Systems, 20 January 2014.

[51] See http://www.fiercewireless.com/tech/press-releases/joint-gph-us-embassy-microsoft-press-release

[52] See http://www.tenet.ac.za/tvws

[53] Hart, Arno, TENET, "Cape Town TV White Space Trial," presentation to ITU-R WP1B workshop on Spectrum Management Issues on the Use of White Spaces by Cognitive Radio Systems, 20 January 2014.

[54] Ibid, slide 27.

[55] Feng, Zhiyong, Beijing University of Posts and Telecommunications, "Cognitive Cellular Systems in China: Challenges, Solutions and Testbed," presentation to ITU-R WP1B workshop on Spectrum Management Issues on the Use of White Spaces by Cognitive Radio Systems, 20 January 2014.

[56] Ibid, slide 14.

[57] Government Accountability Office, "Potential Spectrum Interference Associated with Military Land Mobile Radios," GAO-06-172R, 1 December 2005.