COGNITIVE RADIO NETWORKS: A PRACTICAL PERSPECTIVE

WORLDWIDE TRENDS IN REGULATION OF SECONDARY ACCESS TO WHITE SPACES USING COGNITIVE RADIO

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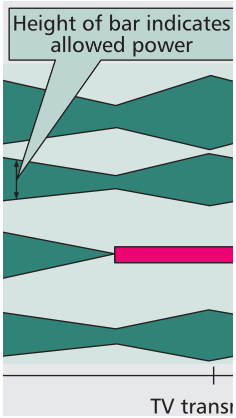

The authors review the state-of-the-art in worldwide regulation of cognitive radio-based secondary access to radio spectrum. Emerging regulatory trends in the United States, UK, Europe and elsewhere are reviewed and compared.

ABSTRACT

We review the state of the art in worldwide regulation of cognitive radio-based secondary access to radio spectrum. Emerging regulatory trends with regards to incumbent protection and detection, operation parameters of cognitive radio, and secondary licensing models in the United States, United Kingdom, Europe, and elsewhere are reviewed and compared. Particular emphasis is given to cognitive radio operation in unused portions of TV bands, the so-called TV white spaces. Initial views on regulatory feasibility of secondary access to civilian radar and military bands are presented.

INTRODUCTION

The demand for wireless broadband services is growing rapidly. Between 2008 and 2010 mobile data traffic grew by 280 percent [1], and this increase is predicted to continue for several years, almost doubling annually over the next five years [2]. Key drivers in this rapid growth include the rollout of fourth generation (4G) wireless technologies, and the increased popularity of WiFi and Wi-Fi enabled smartphones, tablets, and other mobile devices. Furthermore, the expected huge growth in machine-to-machine (M2M) wireless communications over the next decade could result in a considerable increase in aggregate traffic on wireless networks [3, 4].

The need for radio spectrum to fulfill the above demand for wireless broadband services is evident [3, 4]. Cognitive radio [5] is currently being evaluated by regulators as the technology that would enable dynamic reuse of already licensed but spatially or temporally unused spectrum, thereby increasing spectrum availability for new applications. In particular, in both the United States and United Kingdom a regulatory framework for cognitive access to unused portions of TV spectrum, the so-called TV white spaces (TVWS), is well underway. In many other countries the opening of TV and other bands for secondary access is being debated and evaluated by regulators and policy makers.

The above regulatory developments are posing an array of new research challenges to cognitive radio technology that need to be addressed prior to exploitation. Consequently, an understanding of current and emerging regulatory requirements for operation of cognitive radio is of great interest to researchers in industry and universities working on commercial applications of this technology.

The aim of this article, therefore, is to review and compare the state of the art in worldwide regulation of cognitive radio access to secondary spectrum. In particular, we attempt to provide a "unified" picture of the current and emerging regulatory trends in the United States, Europe, and elsewhere with respect to incumbent detection and protection mechanisms, operation parameters of cognitive radios, and secondary licensing models. Particular emphasis is given to regulation of cognitive radio access to TVWS. However, we believe that the discussion presented in this article is also relevant to future regulation of secondary access in other bands.

The work presented in this article summarizes our results on regulatory assessment of secondary spectrum access, which was undertaken within the EU FP7 project Quantitative Assessment of Secondary Spectrum Access (QUASAR) [6]. In addition to publicly available regulatory documents, our work draws on a range of other resources. These included responses to a *Regulatory Questionnaire* that was sent to QUASAR's regulatory partners, BNetzA (Germany), FICORA (Finland), PTS (Sweden), Ofcom (UK), as well as representatives of the FCC (USA), iDEA (Singapore), and KCC (Korea), and presentations and discussions at a one-day QUASAR regulators and industry workshop held at BT's headquarters in London in November 2010 [6].

The rest of this article is organized as follows. Some regulatory essentials on protection of incumbent systems are reviewed. We provide an overview of the current and emerging trends in

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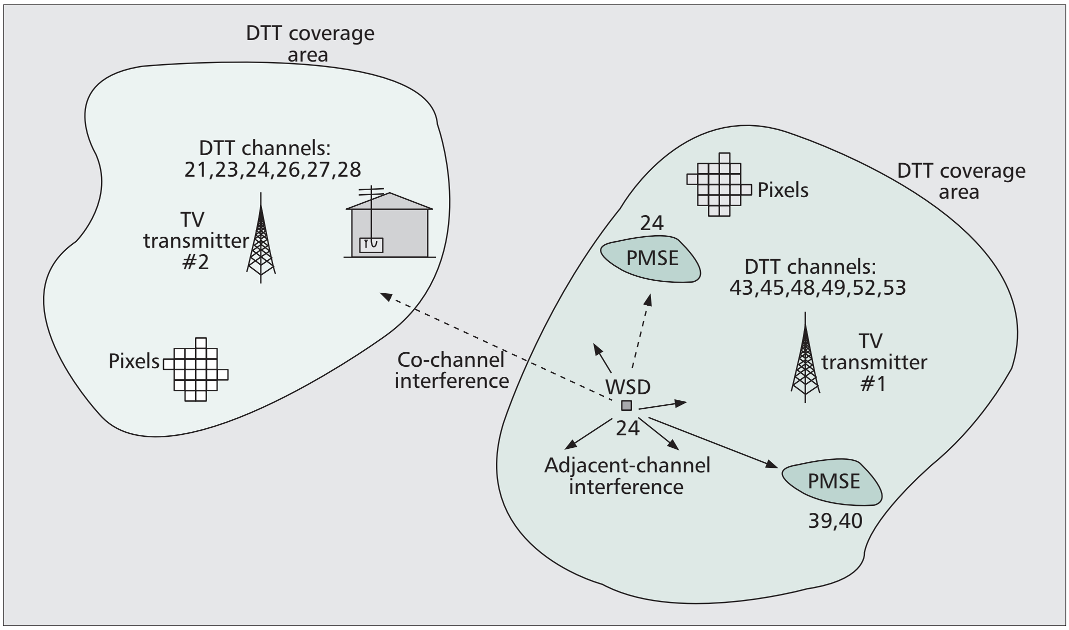

Figure 1. *Illustration of the operation of a white space device in unused TV broadcasting channels (courtesy of Ofcom).*

Secondary operation of cognitive radios in TV bands is conditioned by regulators on the ability of these devices to avoid harmful interference to incumbents, which in addition to TV stations include program making and special event users, such as wireless microphone users.

regulation of secondary access in the United States, United Kingdom, Europe, and elsewhere. This is followed by a discussion of remaining regulatory challenges and future directions. We then conclude this article.

REGULATORY ESSENTIALS FOR PROTECTION OF INCUMBENTS

Large portions of the UHF (and VHF in the United Sates) frequencies are currently used for delivery of TV broadcasting services. In most developing countries a switchover from analog to digital broadcasting is either already completed or underway, while in other countries analog systems are still in use. In both situations not all available frequencies are used in all locations, but with a frequency plan — necessitated by the fact that adjacent channels cause interference. Consequently, at any given location, there are a number of unused channels that could be used on a secondary basis for other applications which have relatively much lower radiation power than TV transmitters; these are *TV white spaces* (Fig. 1 is an illustration of this concept).[1]

Secondary operation of cognitive radios in TV bands is conditioned by regulators on the ability of these devices to avoid harmful interference to incumbents, which in addition to TV stations include program making and special event (PMSE) users, such as wireless microphone users. Furthermore, successful operation in these bands relies on the ability of cognitive radios to reliably detect and use TVWS. Several approaches have been proposed and investigated that aim at achieving these dual objectives. So far the following main methods have been considered and evaluated by a number of regulators: geolocation databases, spectrum sensing, and beacons. In the following we briefly examine these methods.

GEOLOCATION DATABASE

In this approach, to find out which TVWS frequencies are available for its operation at a given location and time, a cognitive radio (also called a white space device [WSD]) queries a central database with its location and other device specifications, such as device type, antenna height, and required service area. The geolocation database then uses this information along with a database of location, transmit power, frequencies, and antenna radiation patterns of all TV transmitters to perform a set of propagation modeling calculations [7]. The outcome of these calculations is a list of available TVWS channels that could be used by the requesting device without causing harmful interference to TV services, accompanied by limits on allowed transmit powers, and possibly a time validity parameter for each channel. Some of these channels may be already in use by PMSE at that location, in which case they are excluded for use by WSD.

Protection via a geolocation database is mainly applicable to incumbent systems that have usage patterns which are either fixed in time or vary slowly (e.g., over hours) such that information stored in a database does not require frequent updating. Furthermore, devices need to know their location with a level of accuracy prescribed by regulators (e.g., 50–100 m for TVWS access). For outdoor applications GPS could be used to support location awareness, but in the case of indoor applications penetration of GPS signals deep inside buildings is problematic. Finally, to access the database in the first place a device needs either to be connected to the Internet via a wired link or could establish a wireless link that does not require secondary spectrum.

Some of the above issues could be addressed in master-slave communication architectures where a master device, such as a Wi-Fi access point [8] or an eNodeB in a cellular network, is

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[1] *With the completion of the switchover from analog to digital terrestrial transmission, a large portion of TV broadcasting bands have become completely cleared and could be used for other services. These frequencies are known as digital dividend and should not be confused with TVWS.*

already connected to the Internet via a wireless or fixed link and can also geolocate itself. The master node then uses its location to query the geolocation database about available secondary spectrum within a predefined service range. Based on this information, it then instructs a set of slave nodes (e.g., handsets or laptops) on the frequencies they could use.[2]

One key problem with cooperative sensing is that the gains compared to a single sensor depend on location and number of sensors, which will typically be random. Thus, it is difficult to establish firm lower bounds for the gains over single sensor scenarios.

SPECTRUM SENSING

In the sensing method devices autonomously detect the presence (or absence) of primary system signals using a detection algorithm. Detection of primary signals could be subject to the so-called hidden node problem [8], which occurs when there is blockage between the secondary device and a primary transmitter, resulting in a situation where a cognitive radio may not detect the presence of a primary signal and starts using an occupied channel, hence causing harmful interference to primary receivers. To solve this problem cooperative sensing algorithms have been proposed where measurements performed by multiple secondary devices are combined in order to achieve a higher sensing level than is possible with a single device [8, references therein]. One key problem with cooperative sensing is that the gains compared to a single sensor depend on location and number of sensors, which will typically be random. Thus, it is difficult to establish firm lower bounds for the gains over single sensor scenarios, which is necessary to take those gains into consideration when defining a regulatory framework.

BEACONS

With the beacon method, cognitive radios only transmit if they receive an enabling beacon granting them use of vacant channels. Alternatively, a cognitive radio may transmit as long as it has not received a disabling beacon denying it use of these channels. One issue with the beacon approach is that it requires a beacon infrastructure to be in place. Furthermore, beacon signals could be lost due to mechanisms similar to the hidden node problem described above.

WORLDWIDE REGULATION OF SECONDARY ACCESS TO TV WHITE SPACES

THE UNITED STATES

In the United States the FCC proposed to allow secondary access by cognitive radio devices to TV bands in 2004. In November 2008 the FCC adopted a Second Report and Order [9, 10] in which it allowed unlicensed operation in TV bands at locations where frequencies were not used by licensed services. The FCC permitted both fixed and personal/portable unlicensed devices to operate in TV bands. Furthermore, the FCC decided to proceed with regulation of both sensing and geolocation approaches for incumbent protection. However, it required that devices that incorporate geolocation and database access must also listen (sense) to detect the signals of TV stations and PMSE.

In a ruling published in September 2010 [11], the Commission eliminated the sensing requirement for secondary devices with geolocation capability. The FCC also issued a call for proposals for geolocation database providers in September 2010. After evaluating the responses received from industry, the FCC conditionally designated in January 2011 nine commercial entities as TV bands database administrators [12]. Based on detailed information received from these entities following their filings, the FCC has granted so far preliminary approval for operation to two of the nine administrators, SpectrumBridge Inc. and Telcordia (which was recently acquired by Ericsson).

The FCC has established two classes of TV bands device: those that may establish a network (called Fixed or Mode II) and those that may join a network (Mode I), and permitted Fixed and Mode I plus II devices (also called personal/portable) to operate in the TV bands. Fixed devices may transmit at up to 4 W effective isotropic radiated power (EIRP).[3] They are allowed to operate on any channels between 2 and 51 except channels 3, 4, and 37, and are subject to a number of other conditions such as a restriction against operation on the same channel (co-channel) or on the first channel adjacent (adjacent channel) as a licensed TV station. Fixed devices must contact a geolocation database to obtain a channel list before operating and re-check the database at least once a day. Personal/portable devices may operate in either Mode I (operating only on channels available through either a fixed or Mode II device) or Mode II when relying on internal geolocation and database access to determine available channels at its location. Mode I and II-type personal/portable devices may operate on any unoccupied channel between 21 and 51, except channel 37, and may use up to 100 mW EIRP, except that operation on the first adjacent channel to TV stations is limited to 40 mW EIRP.

Sensing-only WSDs are also allowed by the FCC. However, a sensing-only WSD is limited to 50 mW transmit power and must be able to detect ATSC digital TV signals and NTSC analog TV signals at –114 dBm (in a 6 MHz band) and to cease transmission within 2 s of signal detection. In addition, a sensing-only WSD must be able to detect wireless microphone signals at –107 dBm.

The FCC has stipulated strict out-of-band emission limits for WSD as compared to WiFi. This is to protect incumbent systems both inside and outside (e.g., Long Term Evolution [LTE]) TV bands. The most recent ruling by the FCC requires that the adjacent channel emission limit for each of the above-mentioned device categories should be –72.8 dB below the maximum power permitted for that device category. The resulting out-of-band emission limits are summarized in Table 1.

We note that current FCC rules allow for transmission by a WSD on *multiple white space channels*. This enables bonding of several (not necessarily contiguous)white space channels, which is required to support high-bandwidth applications such as HDTV streaming in home environments or ultrafast wireless broadband access.

Regarding devices requiring higher-power

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[2] Work on standardization of protocols to access white space databases for the Internet is currently being carried out in the IETF Working Group PAWS.

[3] Fixed WSD may transmit a maximum of 1 W into one or more TVWS channels with antenna gains up to 6 dBi allowed, thus permitting up to 4 W EIRP.

operations (e.g., for cellular applications), the FCC states that [11] "we also understand that there may be situations where radio communications facility could operate at higher power in TV white spaces without causing interference. However, we continue to conclude that because the extended range of such devices would significantly increase the potential for interference and also make it more difficult to identify sources of interference, it would not be appropriate to allow higher power for unlicensed TV band devices at this time." It then concludes that "Indeed, such [high power] operation would be more appropriate under a licensed regime of regulation.

The FCC report [11] includes a detailed discussion of whether secondary access to TVWS should be licensed, license exempt, or subject to light licensing. It concludes that the best way to facilitate innovative new applications is via license exemption and that licensing would not be practicable for many of the new applications envisaged. The report also notes that any licenses would be difficult to define and subject to change (e.g., if television coverage was replanned), so the rights awarded would be rather tenuous.

So far the U.S. regulator has mainly been considering secondary access to TV bands. There are some indications, however, that the FCC is also considering secondary access to other bands, including the federal spectrum, in particular for mobile broadband applications. For example, the FCC has released a Notice of Inquiry on "Promoting More Efficient Use of Spectrum Through Dynamic Spectrum Use Technologies" [13], which is soliciting comments on how to create incentive to facilitate dynamic spectrum use in other bands.

THE UNITED KINGDOM

The U.K. regulator, Ofcom, issued a statement on 13 December 2007 [14] where it considered for the first time the use of interleaved spectrum (TV white spaces) by exempt-exempt devices. It concluded that it should allow exempt-exempt access to TVWS as long as the regulator was satisfied that it would not cause harmful interference to licensed users, including digital terrestrial television (DTT) and PMSE.

Subsequently, Ofcom published a consultation on 16 February 2009 [15]. This predominantly consulted on sensing threshold levels that would be needed for exempt-exempt devices making use of sensing only. In a follow-up statement [16], Ofcom evaluated three mechanisms for identification of vacant TV bands: sensing, geolocation, and beacons. It concluded that beacon transmission was inferior to the other two approaches and therefore would not be considered further. The main reason is that this approach required the establishment of a costly infrastructure while at the same time not being able to guarantee that harmful interference could be avoided at all times (due to the possibility of beacon signals getting lost). Furthermore, Ofcom concluded that there were advantages and disadvantages to both sensing and geolocation, and decided to proceed with regulation of both approaches. However, it concluded that in the short term the most important mechanism for spectrum detection would be geolocation. The operation parameters for sensing-based and geolocation-based WSD are summarized in Table 2.

Type of WSD	Power limit	Adjacent channel limit(100 kHz)
Fixed	30 dBm (1 W)	–42.8 dBm
Personal/portable (adj. channel)	16 dBm (30 mW)	–56.8 dBm
Sensing only	17 dBm (40 mW)	–55.8 dBm
All other personal/portable	20 dBm (100 mW)	–52.8 dBm

Table 1. *WSD adjacent channel emission limits required by the FCC.*

Ofcom released in 2011 a Statement [17] where it described in detail its proposed implementation of the geolocation process. Ofcom has specified two types of WSD: master and slave devices. Slave devices receive the relevant information regarding available channels and transmit power levels from a master device, but do not contact the database themselves. Master devices are assumed to have geolocation capability and be able to connect to a geolocation database. Unlike the FCC, which has prescribed fixed transmit levels for each class of WSD, Ofcom has chosen a more flexible approach where the maximum WSD transmit power is determined per device and per channel based on a prescribed level of protection the regulator offers to DTT and PMSE services. We examine this important difference between the two approaches in the following section.

Following the above statement, Ofcom has established a TVWS technical Working Group in order to create a U.K.-specific framework for the regulation of WSD operating under geolocation databases. This work is expected to be finalized in 2012, with the first commercial applications in the United Kingdom appearing by 2013.

As of 2012 Ofcom has yet to specify the out-of-band emission limits of WSD. However, it is likely that it may adopt a somewhat different approach to the FCC: Instead of specifying absolute limits on adjacent channel emissions Ofcom may specify the ratio between the in-band and out-of-band emission of WSDs.

EUROPE

On the European level, detailed technical and regulatory work on cognitive radio is currently being carried out in several working groups of Conférence Européenne des Administrations des Postes et des Télécommunications (CEPT). At the same time the Radio Spectrum Policy Group (RSPG), which advises the European Commission on development of radio spectrum policy on a strategic level, has been addressing high-level policy issues of cognitive radio.

CEPT's SE43 project team has developed a new ECC Report 159, "Technical and Operational Requirements for the Possible Operation

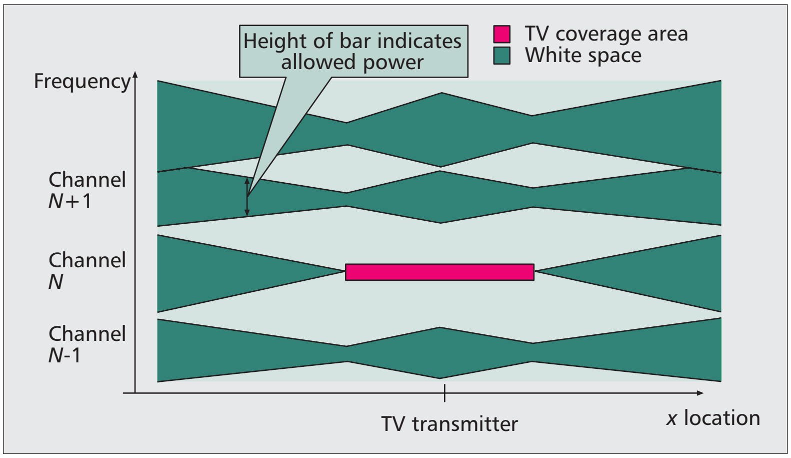

Figure 2. *Schematic illustration of the basic principle of the SE43 approach.*

of Cognitive Radio Systems in the 'White Space' of the Frequency Band 470–790 MHz" [18], which was finalized and approved on 28 January 2011.[4]

The SE43 draft report was developed in order to ensure protection of the incumbent radio services. While three cognitive techniques (sensing, geolocation database and beacons) were considered at the start of the SE43 study, most of the effort was devoted to the assessment of the feasibility of and technical requirements for the sensing and geolocation techniques.

With regard to protection of the broadcasting services the sensing thresholds recommended by SE43 were derived for a limited number of scenarios taking into account a range of potential DTT receiver configurations in Europe. The values so obtained were in the range from –91 to –155 dBm, some of which are far too low to be implemented with the current sensing technology. Moreover, the report concludes that even those low detection threshold values do not guarantee a reliable detection of the presence/absence of the broadcasting signals at a distance corresponding to the interference potential of a WSD. This has led the SE43 working group to the conclusion that "the sensing technique investigated, if employed by a stand-alone WSD does not appear to be reliable enough to guarantee protection of nearby DTT receivers using the same channel" [18]. Furthermore, the report concludes that "The use of a geolocation database to avoid possible interference to DTT receivers appears to be the most feasible option. In cases where the use of a geolocation database can provide sufficient protection to the broadcast services, sensing is not required. There may be some potential benefit in using a combination of sensing and geolocation database to provide adequate protection to DTT receivers but these benefits would need to be further considered."

With regard to the protection of PMSE from WSD interference, the report concludes that "spectrum sensing is currently considered as a problematic approach," and therefore, "use of a geolocation database appears to be the most feasible approach considered so far." However, the report points out a number of practical questions, such as how PMSE users will enter data into the system, what information should be stored, and how often the WSD must consult the database, qguxg still require resolution. Although not considered in all details, the report concludes that the disable beacon concept may be an approach that could help to overcome some of the difficulties associated with sensing of the PMSE users.

Finally, the report sets up the principles and defines the requirements for the operation of WSD under the geolocation approach. Specific requirements are provided for WSD deployment using the aforementioned master-slave architecture. It also provides guidance to administrations on a general methodology and algorithms for the conversion of the information characterizing incumbent systems (e.g., DTT transmitter details and coverage maps) into a list of allowed frequencies and associated maximum transmit powers to be communicated to the WSD.

After approving the SE43 draft report in Jan-

Cognitive parameter	Value (sensing)	Value (geolocation)
Signal detection sensitivity for DTT	–120 dBm (8 MHz channel)	—
Signal detection sensitivity for wireless microphones	–126 dBm (200 KHz channel)	—
Maximum transmit power	4 dBm (adjacent channel) to 17 dBm (next adjacent channel)	As specified by database
Transmit power control	Required	Required
Bandwidth	Unlimited	Unlimited
Out-of-band performance	< –46 dBm	< –46 dBm
Minimum time between sensing	< 1 s	—
Location accuracy	—	Nominally 100 m

Table 2. *The operation parameters for sensing-based and geolocation-based cognitive radios as proposed by Ofcom [16].*

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[4] *See also www.ecodocdb.dk where this and all other ECC reports are available for download.*

uary 2011, CEPT WG SE (the parent group of SE43) developed a new work item for SE43 and suggested the following issues to be addressed in a short-term timeframe:

- Elaboration of the approaches combining the geolocation database and spectrum sensing
- Studies on the impact from WSD on services in the bands adjacent to 470–790 MHz
- Identification of a common set of parameters required to calculate location-specific WSD power levels

In the meantime, SE43 has initiated development of two complementary ECC reports that are expected to be finalized in September 2012. One key advance provided by these reports is that protection of services in adjacent bands requires some additional limitations on WSDs which need to be implemented in the geolocation database.

Regulations Elsewhere

In Korea, the national regulator, KCC, announced in 2011 a plan for TVWS regulation [19]. According to this plan, a technical framework for the protection of TV broadcasting against interference from WSDSs will be established in 2012. Licensing schemes and other regulatory policies will also be investigated in 2012, followed by trials in limited areas taking place in 2013.Geolocation databases are expected to be an essential component of these trials, while spectrum sensing will be investigated later. Nationwide white spaces services are expected to appear in Korea by 2014.

Industry Canada released in August 2011 a consultation [21] seeking comments on all aspects of policy and technology related to operation of WSD in TV bands. Industry Canada has not yet proposed detailed operational parameters for WSD. However, it is proposing to focus initially on the use of geolocation databases for incumbent protection and recommends that a Canadian database should be developed.

In Finland, FICORA issued a statement in 2009, which states that cognitive radios are permitted to operate in the 470–790 MHz frequency band provided they do not cause interference to other system in the band. Based on this the Finnish regulator has already granted several short-term test licenses and is working currently on a complete regulatory framework.

Elsewhere, the national regulators in Japan and Singapore, Finland, and South Africa have created special zones for experimentation by industry of secondary access technologies prior to adopting a regulatory framework. Finally, the Australian Regulator, ACMA, is "maintaining a watching brief on the development of white space technologies."[5] However, no timeframe for their introduction in Australia has been set as of 2012.

Discussion and Future Directions

Comparison of SE43 and FCC Rules

There are important differences between the Ofcom/SE43 and FCC approaches in implementing secondary access to TVWS. Ofcom/SE43 has chosen a more flexible approach, while the FCC approach is more prescriptive. While the FCC imposes a 4 W maximum transmit power on WSD, Ofcom/SE43 has left the maximum transmit power to be determined by the database depending on distance to the nearest TV coverage area and adjacent channel interference potential. Although the methodologies proposed by Ofcom and CEPT SE43 are very similar, the following discussion and comparison is based on the SE43 methodology as described in [18].

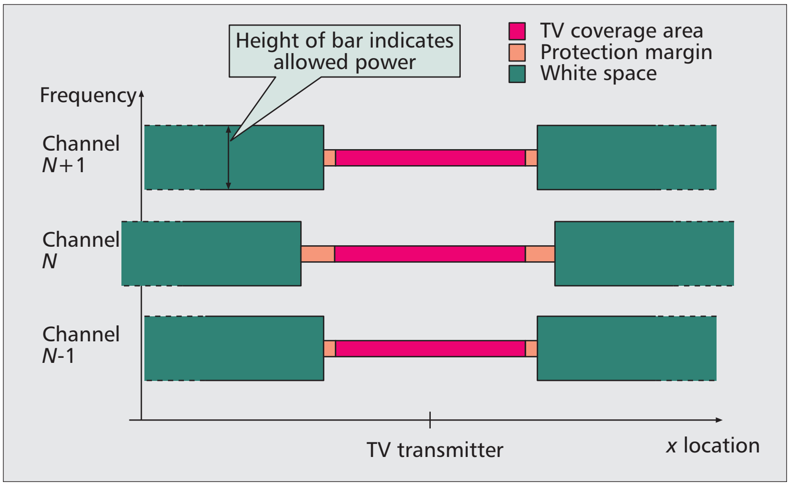

Figure 3. *Schematic illustration of the FCC rules.*

In the SE43 method white space availability is defined indirectly via a location-dependent maximum permitted transmit power for WSD (Fig. 2). Within a TV transmitter's coverage area, the permitted co-channel transmit power is zero. Outside the coverage area, it gradually increases with increasing distance from the coverage edge. If WSDs operate on frequencies adjacent to a TV transmitter's operating frequency, they are in principle allowed to transmit within the coverage area, but have to adjust their transmit power so that the interference they generate stays below the limit TV receivers can tolerate based on their respective wanted signal level. That is, WSDs located at the edges of the adjacent channel TV transmitter's coverage area will have a lower transmit power limit than the ones located in the center of the TV coverage area. The same principle is also applied to non-adjacent channels, but due to the increase of the isolation between the respective channels (e.g., the second adjacent channel will have less stringent transmit power limits at the same location than the first adjacent channel). Other than these channel and distance separation based power limits, there are no further limitations on transmit power.

In the FCC rules the permitted maximum transmit power of WSDs is fixed (different limits are defined for different device types; Fig. 3). Around each TV transmitter's coverage area there is an additional protection distance in which WSDs are not allowed to operate at all on a co-channel, and outside this distance the allowed transmit power immediately goes up to the maximum allowed value. This principle is also applied to the first adja-

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[5] *See "Clearing the Digital Dividend: Decisions on Planning Principles for Restacking Digital Television Channels," Australian Communications and Media Authority, May 2011.*

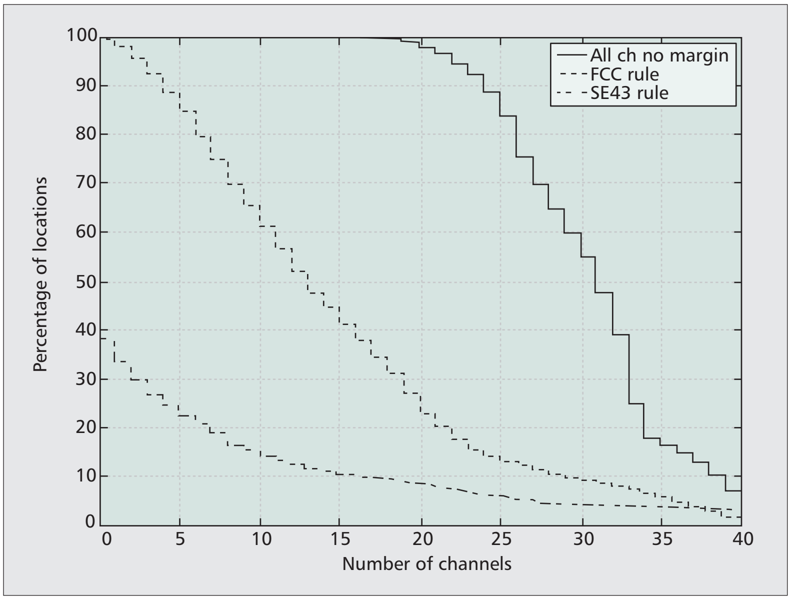

Figure 4. *CDF of the number of TV channels available for white space usage in Sweden compared for SE43 approach and FCC rules.*

cent channel, only the protection distance is smaller. Beyond the first adjacent channel there are no limitations from the viewpoint of one particular transmitter, but of course there may be other transmitters operating on other frequencies that imply a limitation on those frequencies.

In Fig. 4 the number of available white space channels is compared (using the example of Sweden) to the FCC and SE43 approaches, respectively. For the SE43 approach it is assumed that WSDs have an emission mask that is similar to current LTE equipment as standardized by the Third Generation Partnership Project (3GPP), which implies that adjacent channel interference is non-negligible for up to nine adjacent channels. This leads to a significantly higher probability of being limited by an adjacent channel interference scenario, for which a very low minimum coupling loss (MCL) has to be assumed for calculating the maximum WSD transmit power.

This example illustrates that, in general, the availability of white space could be very sensitive to the details of the protection rules and methodologies imposed by regulators, and could therefore strongly vary between different administrative domains.

GEOLOCATION DATABASES VERSUS SENSING

The general consensus among Ofcom, the FCC, and CEPT's SE43 working group is that in the short term the use of geolocation databases is technically the most feasible approach since currently sensing techniques employed by standalone devices either cannot guarantee reliable detection of primary systems or require expensive cognitive equipment. Also, there seems to be a general consensus that implementation of secondary sharing based on beacons is problematic due to the required infrastructure that needs to be in place and maintained.

Although the geolocation database approach provides a good short time solution for TVWS access, some regulators (e.g., the Swedish regulator PTS) are encouraging industry to focus on longer-term innovation and other innovative mechanisms, including cooperative sensing, which could also be applicable to other secondary access scenarios beyond TVWS.

OPTIONS FOR SECONDARY LICENSING

Both the FCC and Ofcom have so far only considered the license-exempt approach. While there is recognition by these regulators that this model may not fit all future industry use cases (e.g., those who may require higher transmit powers or some form of long-term guaranteed availability, e.g., rural broadband), implementing other licensing options is perceived as too restrictive to promote innovation in the use of TVWS. Furthermore, some of the strongest proponents of white space are not interested in operating networks themselves but are rather aiming at operating geolocation databases and/or enabling ubiquitous and low-cost/free wireless broadband connectivity, with the expectation that consumers themselves would buy and operate their own equipment (e.g., white space routers). Such industry players are naturally more interested in an unlicensed regime that does not lock in end users to any license holder.

However, both Ofcom and the FCC seem to be willing to consider the use of other license types in the longer term. This could turn out to be an important enabler for larger investments into communication infrastructure relying on white space frequencies, since both network planning and return on investment in such scenarios would greatly benefit from stable frequency availability, as well as encourage manufacturers to develop white space equipment due to expected larger market volume with better economies of scale.

The geolocation database approach can provide regulators with the necessary mechanism for enabling such alternatives to the exempt model. For example, longer-term exclusive license or spectrum reservation in a given region could be implemented simply by putting the lifetime field of the available TVWS frequencies in a given region to infinity for one user while denying admission to any other users. We note that a somewhat similar approach to licensing secondary access, called Authorized Share Access (ASA), has been proposed recently [22], with backing from industry players like Nokia and Qualcomm.

Such new licensing approaches would significantly benefit from a feedback mechanism in the communication between WSDs and the database. Without feedback from WSDs the geolocation database is agnostic to the spectrum utilization by WSDs and is thus not able to consider usage by other white space users in determining the locally available frequencies. The FCC rules currently do not mandate WSDs to report their channel usage to the geolocation database. However, feedback mechanisms have recently been proposed as mandatory requirements to WSDs both on the European level and in the United Kingdom.

FAIRNESS AND COEXISTENCE IN WHITE SPACES

A key issue of the licensed-exempt model (also known as spectrum commons) is that fair spectrum sharing can effectively only be achieved when all devices are using the same set of sharing protocols. However, since there are several (possibly competing) technologies under development for white spaces, it is unlikely that these can share the spectrum among each other in an equitable manner. This means that regulators either have to leave the fairness problem for industry to solve (which may be in conflict with the principle of technology neutrality since it implicitly favors the first technology that comes to the market) or they have to specify a set of sharing protocols (also known as politeness rules or spectrum etiquette) themselves. Since regulators typically lack both the resources and the experience required for standardization, it appears questionable if this latter option would be successful in practice. In addition to fairness, quality of service provision in TVWS is highly desirable for important applications of the technology, including broadband wireless access for rural communities and smart grid communications, but is difficult to achieve without coordination.

In this context, one important industry initiative that is worth mentioning is the IEEE 802.19 standardization project [23], which aims to specify radio-technology-independent methods for coexistence among dissimilar or independently operated wireless devices and networks in order to enable better use of spectrum and better quality of service in TVWS.

CONTROLLING AGGREGATE INTERFERENCE IN WHITE SPACE

While a single WSD could be assumed to operate safely under the control of a geolocation database, future scenarios may involve large numbers of such devices (e.g., WiFi-like access points or cellular base stations), whose aggregate emissions in white space channels could cause harmful interference to nearby PMSE or TV receivers. The standard regulatory approach to deal with such aggregate interference issues, which is being considered in the SE43 group, is to include an extra protection margin when computing the permissible transmit power of WSDs in a given channel. This additional margin then is supposed to account for the possibility of aggregate interference that has resulted from multiple WSDs already using that channel. However, as shown in [24], a conservatively chosen margin could severely limit the maximum transmit power of WSDs. On the other hand, choosing the margin too low increases the risk of harmful aggregate interference.

One possible solution to this problem is to allow a geolocation database to allocate transmit power to WSDs dynamically, based on their estimates of aggregate interference. Consequently, in a region where WSD deployment is sparse, higher transmit levels could be allocated to devices, while in high-density deployment scenarios transmit powers could be reduced, such that in both cases the aggregate interference is kept below an acceptable regulatory cap [24].

GENERALIZING THE WHITE SPACE CONCEPT

With the prospect of an imminent "spectrum crunch" resulting from a phenomenal growth in wireless data, there is currently great interest in spectrum sharing from industry and administrators alike [3, 4]. Therefore, a successful introduction of secondary access to TV bands is bound to facilitate and stimulate secondary sharing of spectrum in other bands. The 5150 MHz to 5350 MHz and 5470 MHz to 5725 MHz radar bands are already open to secondary access by WLAN devices which use dynamic frequency selection (DFS) to protect radars from harmful interference. Other civilian radar bands in the 960–1215 MHz, 2700–2900 MHz and 2900–3100 MHz appear to be likely candidates for cognitive radio use [25]. In particular, in many cases the locations of radars are static and public knowledge, making a geolocation database approach to incumbent detection and protection possible. Furthermore, since for radars receiver and transmitter antennas are collocated, the hidden node issue that plagues sensing-based access to TVWS is not a major problem.

Other potential candidates for cognitive access are military bands, which in most countries take up a large fraction of the radio spectrum used for public services. There are legitimate concerns regarding the potential risks to safety/national security of secondary sharing these bands that need to be carefully considered and researched.

CONCLUSION

This article has reviewed the current status and emerging trends in regulation of secondary access to radio spectrum in the United States, United Kingdom, mainland Europe, and elsewhere. Particular emphasis was given to the status of technology-centric secondary access enabled by cognitive radio in unused TV bands, or TV white spaces.

A regulatory framework for secondary access to TVWS has been finalized in the United States, is near completion in the United Kingdom, and is also well underway on a European level within CEPT, and has been initiated in Canada, Finland, and Korea. Regulators in a number of countries, including Singapore, Japan, and South Africa, are taking the approach of allowing testing and evaluation by industry of cognitive radio techniques, sensing, and geolocation in these bands prior to adopting regulation.

The "first wave" of regulations of secondary access has primarily focused on putting in place the required mechanisms and framework that ensure protection of primary systems against harmful interference from a "single" cognitive radio. With growing interest from the industry in exploiting white space spectrum for a range of applications, we expect that some of the focus of regulations would now shift to addressing challenges in secondary sharing of white spaces among heterogeneous and potentially competing technologies. These include fairness and coexistence issues, secondary licensing models, "secondary spectrum usage rights," and aggregate interference regulation, and need to be addressed jointly by regulators, industry, and the research community.

Both the FCC and Ofcom have so far only considered the license-exempt approach. While there is recognition by these regulators that this model may not fit all future industry use cases, implementing other licensing options is perceived to be too restrictive to promote innovation in the use of TVWS.

With a growing interest from the industry in exploiting white space spectrum for a range of applications, we expect that some of the focus of regulations would now shift to addressing challenges in secondary sharing of white spaces among heterogeneous and potentially competing technologies.

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