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Current Trends in Regulation of Secondary Access to TV White Spaces Using Cognitive Radio

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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, UK, Europe and the Asia Pacific region are reviewed and compared. Particular emphasis is given to cognitive radio operation in spatially 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.**

Keywords-component; spectrum regulaion; cognitive radio; TV White Spaces; Secondary spectrum access

I. Introduction

The demand for wireless broadband services is growing rapidly, primarily for mobile connectivity but also for fixed and nomadic broadband applications. During the last two years the mobile data traffic grew by 280% [1], and this increase is predicted to continue for several years [2], doubling annually over the next five years. Key drivers in this rapid growth include the maturation of third generation (3G) mobile wireless network services, the roll-out of fourth generation (4G) wireless technologies, the increased popularity of Wi-Fi-enabled smartphones and other mobile computing devices such as tablets. Furthermore, over the next decade a huge increase in the machine-to-machine (M2M) wireless communications is expected, and the resulting aggregate traffic on wireless networks could be enormous [3].

The need for radio spectrum to fulfill the above demand for wireless broadband services is evident, see, e.g. [3]. Cognitive radio [4, 5] is being currently evaluated by regulators as the technology that would enable dynamic re-use of already licensed but spatially or temporarily unused spectrum, thereby increasing spectrum availability for new applications without the need for lengthy spectrum relocations. In particular, both in the US and UK 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 which 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 paper, 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 the Asia Pacific region 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 paper is also relevant to future regulation of secondary access in other bands. The work presented in this paper summarizes our initial results on regulatory assessment of secondary spectrum access in Europe and elsewhere, which was undertaken within the EU FP7 project QUASAR (Quantitative Assessment of Secondary Spectrum Access) [6].

The rest of this paper is organized as follows. In Section II some regulatory essentials of cognitive radio-based secondary spectrum access are briefly reviewed. In Section III the methodology used in the current study is outlined. This is followed by an overview of the current and emerging trends in regulation of secondary access in the United States, Europe and the Asia Pacific region, and a discussion of our findings. The paper is concluded in section IV.

II. Incumbent Protection Mechanisms

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 wireless microphones and other PMSE (Programme Making and Special Event) users. Furthermore successful operation in these bands relies on the ability of cognitive radios to reliably detect and use secondary spectrum opportunities in these bands. Several approaches have been proposed and investigated that aim at achieving these dual objectives. So far the following methods have been considered and evaluated by a number of regulators: geolocation databases, spectrum sensing, data fusion and beacons. In the following we will briefly examine these methods.

A. Geolocation database

In this method to find out which frequencies are available for secondary access at a given location and time, the secondary system queries a central database with its location and other specifications, such as device type and required operation parameters. The geolocation database then performs the required computation on its dataset of incumbent systems in order to find the current spectrum usage in the location of secondary user. It then responds to the requesting device with information on the available spectrum opportunity. This information may contain a list of available channels accompanied by limits on the allowed transmit powers and, possibly, a time validity parameter for each channel.

Incumbent protection via a geolocation database is mainly applicable to incumbent systems that show usage patterns that are either fixed in time or show sufficiently slow, e.g. hours, temporal changes so that information stored in the database does not require highly frequent updating. Furthermore, devices need to know their location with a level of accuracy which is prescribed by regulators, e.g. 50-100 meters 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 the buildings is problematic. Finally, to access the database in the first place a device needs to be either 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 [7] or an eNodeB in a cellular network, is 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 pre-defined 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.

B. 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" [7], 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 measurement performed by multiple secondary devices are combined in order to achieve a higher sensing level than is possible with a single device [8]. Cooperative sensing has been considered by the FCC and Ofcom but as yet these regulators have not defined any operational parameters for devices that use this approach.

C. Geolocation databse combined with sensing (data fusion)

In this approach incumbent detection is performed via a database approach as outlined above. However, information from the database is complemented with spectrum sensing data. The sensing information may be useful to establish an initial connection to the database or to obtain more fine-grained information (in space or time) on available spectrum holes. Finally, spectrum sensing could be used to detect primary users with a more dynamic usage pattern, e.g. wireless microphones operating in TVWS.

D. Beacons

With the beacon method various options could be envisaged. One possibility is that a White Space Device (WSD) may only transmit in a TV channel if it receives an enabling signal (grant beacon) declaring the channel as available for use. Another possibility is that a WSD may use a TV channel unless it receives a disabling signal (denial beacon) declaring the channel as unavailable. A combination of both beacons can also be used in order to improve the reliability of this mechanism.

The beacon signal could be received either from a primary transmitter or provided by a third party who provides beaconing services. One issue with this approach is that it requires either the implementation of beaconing functionality in primary devices, or the availability of a new beaconing infrastructure.

III. World Wide Regulation of Secondary access to TV White Spaces

A. Methodology

To obtain a reasonably "unified" view on the status of TVWS regulation across the world, we made use of a *Regulatory Questionnaire*. The questionnaire was designed in close discussion with QUASAR's regulatory partners. It aimed at seeking views from national regulatory bodies on the current status in regulation of secondary access in their respective countries. We also sought views from regulators on remaining research challenges of cognitive radio.

The questionnaire was sent to QUASAR's regulatory partners, BNetzA (Germany), FICORA (Finland), PTS (Sweden), Ofcom (UK), as well as representatives of FCC (USA), iDEA (Singapore) and KCC (Korea). In addition to responses to our questionnaire, the material presented in this paper draws on publicly available regulatory resources, including discussion papers and reports, public consultations and rule-making documents. Finally, we organized a one day workshop in London on November 29, 2010, where in addition to QUASAR's regulatory partners, representatives from CEPT and the FCC provided updates on the status of regulation across the EU and in the United States, and shared their views with industry stakeholders. The material presented in this Section draws also from presentations and discussions at this workshop, in particular in the Discussion and Conclusion Sections.

B. The United States

In the United States the Federal Communication Commission (FCC) proposed to allow secondary access by cognitive radio devices to TV bands already in 2004 [9,10]. In November 2008 the FCC adopted a Second Report and Order [11, 12] in which it allowed unlicensed operation in TV bands at locations where frequencies were not used by licensed services. The Commission 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 incorporated geolocation and database access must also listen (sense) to detect the signals of TV stations and PMSE .

In a more recent ruling published in September 2010 [13], 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 [14]. The FCC has asked designated administrators to supplement their filings with sufficient detailed information to indicate compliance with FCC rules published in the second MO&O, including security and user privacy.

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 Watts EIRP (effective isotropic radiated power) and 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. Personal/portable devices may operate either in Mode I (operating only on channels available through either a fixed or Mode II device) or in Mode II when relying on internal geo-location 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 are limited to 40 mW EIRP.

The FCC has stipulated rather strict out-of-band emission masks for White Space Devices: in the adjacent channel the power must be 55dB below the highest average power in the channel in which the device is operating. Consequently, real-life implementation of the FCC spectrum mask in current Silicon technology can result in a substantial reduction of the available bandwidth in TVWS channels.

Regarding devices requiring higher power operations, e.g., for cellular applications, the FCC states that [13] "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 [13] includes a detailed discussion about whether secondary access to TVWS should be licensed, licence exempt, or subject to light licensing. It concludes that the best way to facilitate innovative new applications is via licence-exemption (the quasi commons) and that licensing would not be practicable for many of the new applications envisaged. The report also notes that any licences would be difficult to define and would be subject to change (e.g. if television coverage was re-planned), so the rights awarded would be rather tenuous.

So far the US regulator has been mainly 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 where 500 MHz spectrum needs to become available by 2012. For example, the FCC has released a Notice of Inquiry on "Promoting More Efficient Use of Spectrum Through Dynamic Spectrum Use Technologies" [15], which is soliciting comment on how to create incentive to facilitate dynamic spectrum use in other bands.

C. The United Kingdom

The UK regulator, Ofcom, has been at the forefront of promoting secondary access to TV White Spaces in Europe. It issued a statement on 13 December 2007 [16] where it considered for the first time the use of interleaved spectrum (TV White Spaces) by licence-exempt devices. It concluded that it should allow access by licence-exempt devices to TVWS as long as the regulator was satisfied that it would not cause harmful interference to licensed users, including DTT (Digital Terrestrial Television) and PMSE.

Subsequently, Ofcom published a consultation entitled "Digital dividend: cognitive access. Consultation on licence-exempting cognitive devices using interleaved spectrum" on 16 February 2009 [17]. This predominately consulted on sensing threshold levels that would be needed for licence-exempt devices making use of sensing only. In a follow-up statement [18], Ofcom evaluated three mechanisms for identification of vacant TV bands: (1) sensing, (2) geolocation and (3) beacons. It concluded that beacon transmission was inferior to the other two approaches and therefore would not be considered further. The main reason being 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 geo-location, 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 1.

Following the above conclusion, Ofcom published a discussion document entitled "Digital Dividend: Geolocation for Cognitive Access" on 17 November 2009 [19] where it discussed a number of key issues to be addressed in developing a geolocation approach. Following responses from interested parties to this document, Ofcom has released a further consultation on "Implementing geolocation" [20] where it describes in detail its proposed implementation of the geolocation process. As a next step to implementing its proposed geolocation process Ofcom plans to publish a statement on its current position, having considered responses to its consultation. The next steps would include drafting a Statutory Instrument (SI) in order to exempt the appropriate devices from the need for licences. It is also likely to require preparation of a framework for authorizing and regulating the geolocation database service providers.

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 second	_
Location accuracy	_	Nominally 100 metres

Table 1. The operation parameters for sensing-based and geolocation-based cognitive radios as proposed by Ofcom.

D. Europe

Within Europe detailed technical and regulatory work on cognitive radio is currently being carried out in several working groups of CEPT (Conférence Européenne des Administrations des Postes et des Télécommunications). 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 issue of cognitive radio.

CEPT's SE43 Working Group has developed Draft ECC Report 159, "Technical and Operational Requirements for the Possible Operation of Cognitive Radio Systems in the 'White Space' of the Frequency Band 470-790 MHz" [21]. This draft report was in public consultation until 30 November 2010. An SE43 resolution meeting was held in Geneva on 8 December 2010 where elements of the report were revised based on response received from public consultation. The report was finalized and approved on 28th of January 2011 after some limited revisions.

The SE43 draft report was developed in order to provide technical and operational requirements for cognitive radio systems in TVWS in order to ensure protection of the incumbent radio services. Below we provide a summary of the findings of the report. 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 to provide protection to the incumbent radio services.

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" [21]. 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 regards 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, that 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 master-slave architecture. It also provides guidance to administrations on a general methodology and algorithms for the conversion of the information provided by the database, 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 January 2011, CEPT has developed a new work item for the group and has suggested the following issues to be addressed in a short term time frame: (i) elaboration of the approaches combining the geolocation database and spectrum sensing, (ii) studies on the impact from WSD on services in the bands adjacent to the 470-790 MHz, (iii) identification of a common set of the parameters required to calculate location specific WSD power levels.

E. The Asia Pacific Region

In the Asia Pacific region, regulators in Singapore [22], Japan and Korea [23] have started to allow testing and evaluation by industry of cognitive radio techniques, sensing and geolocation, in these bands prior to moving to regulations. For example, the Singapore regulator iDA has established a Cognitive Radio Venue (CRAVE), a testbed for evaluating promising cognitive radio technologies in TVWS by interested parties in industry. The aims of Singapore's CRAVE trials are to study the feasibility of using spectrum from the neighboring countries for WSD trials on a non-interfering basis, and to investigate the performance and impact of WSD in dense-urban environments in Singapore; in particular multi-story built up areas. In Japan MIC (Ministry of Internal Affairs and Communications) has plans to push ahead the technology with the help of "White Space Special Zones" which are expected to spread throughout the whole country by 2012.

F. Discussion

There are important differences between the Ofcom and FCC approaches in implementing secondary access to TVWS. Ofcom have chosen a more flexible approach while the FCC approach is more prescriptive. While the FCC imposes a 4W maximum transmit power on WSD, Ofcom has left the maximum transmit power to be determined by database. Furthermore, Ofcom has proposed to use WSD spectrum emission masks provided by manufacturers while FCC has prescribed a stringent mask.

The general consensus among Ofcom, FCC and CEPT's SE43 working group is that in the short term the use of geo-location databases is technically the most feasible approach since currently sensing techniques, employed by stand-alone 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 in some frequency bands some regulators, (e.g. the Swedish regulator PTS, and the US regulator FCC,) are encouraging industry to focus on longer term innovation and innovative other dynamic spectrum access mechanisms including cooperative sensing. However, one potential issue with cooperative sensing that remains to be addressed by industry/standardization bodies is how to *certify* devices since performance is generally dependent on the number of cooperating nodes and their spatial distribution.

In the Asia Pacific region, the national regulators in Korea, Japan and Singapore are creating special zones for experimentation by industry of secondary access technologies prior to adopting a regulatory framework. This approach is also being followed by the Finish regulator, FICORA.

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Regarding the type of secondary licences to be used for access to TVWS, both the FCC and Ofcom are currently only considering licence-exempt access. 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, other licence types are considered at this stage too restrictive to promote innovation in the use of these bands. However, both Ofcom and FCC seem to be willing to consider the use of other licence types, e.g. for rural broadband, on a case-by-case basis. The geolocation database approach can provide regulators with the necessary mechanism for enabling alternatives to the licence-exempt model of access to white spaces. E.g. longer term exclusive licence or spectrum reservation in a given region could be simply implemented by putting the life-time 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 [25], with backing from industry players like Nokia and Qualcomm.

The successful introduction of secondary access technology in TV bands may stimulate further development in other bands, including radar and military 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 appear to be likely candidates for cognitive radio use [24]. In particular in many cases the locations of the radars are static and public knowledge (See, e.g., [26] for a publicly available database of meteorological radars in Europe). Other potential candidates for cognitive access are military bands. In the United Kingdom, for example, with the application of administrative incentive pricing to public users of spectrum, such as the UK Ministry of Defense (MoD), certain bands are now in process of being made open either through clearing or in a form suitable for sharing. The latter are likely to be eminently suited to the application of cognitive techniques [27].

IV. Conclusion

This paper reviewed the current status and emerging trends in regulation of secondary access to radio spectrum in Europe, the United States and Asia-Pacific. Particular emphasis was given to the status of *technology-centric* secondary access enabled by cognitive radio technology in unused TV bands, or TV White Spaces.

A regulatory framework for secondary access to TVWS is currently well underway in the United States and the UK. On a European level, work within CEPT continues to define technical and operational requirements for cognitive radio access to this spectrum. Furthermore, regulators in a number of countries, including Finland, Singapore and Japan 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.

Effective exploitation of cognitive radio technology for secondary spectrum access requires addressing an array of research challenges, a number of which are posed by the stringent regulatory requirements for incumbent protection. One of these research challenges, high-precision spectrum sensing, has been the subject of intense research. However, in the light of recent regulatory developments, there is need for future research in geolocation databases, indoor positioning systems, and data fusion. Furthermore, most regulatory work so far has been focused on defining operational parameters for *single* cognitive radios. Scenarios involving multiple cognitive radio systems and users pose new challenges in co-existence, secondary spectrum sharing and aggregate interference control [28], which need to be jointly addressed by regulators, industry and the research community.

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