Dynamic Spectrum Access: regulations, standards and green radio policy considerations

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Abstract-Dynamic spectrum access (DSA) technologies are increasingly viewed as a potential solution to improve overall spectral utilisation efficiency and for bridging the digital divide in the rural areas. In particular, DSA technologies have the ability to sense and opportunistically access radio frequency (RF) spectrum that lies fallow at any particular time or space. However, in order to achieve successful deployment of these technologies, spectrum regulators need to implement reforms to their existing spectrum management regulations. In this context, this paper investigates conventional and emerging RF spectrum regulations and standards necessary to realise maximum benefits that such technologies might bring. In addition, this paper considers the ever-growing negative environmental impact caused by the information and communication technologies (ICT) sector. The paper suggests that any new dynamic spectrum management regulations should go hand-in-hand with the promotion of green communications networks policies.

Index Terms—Dynamic spectrum access, DSA, digital divide, ICT, green communications, policies, regulators, RF spectrum, spectral utilisation, spectrum regulators.

I. INTRODUCTION

The first radio to transmit and receive over a range of few metres was demonstrated by Heinrich Hertz in 1888. The term radio frequency (RF) spectrum is often used to refer to the full frequency range from 3 kHz to 300 GHz that may be used for wireless communication. The RF spectrum is one of the scarcest network resources in wireless communications. Over the past few decades, the world has witnessed rapid growth of wireless communication technologies capable of offering multimedia services and applications. This growth has fuelled increased demand for RF spectrum, resulting in the use of additional frequency bands.

Governments around the world have established regulatory agencies (e.g., the Federal Communications Commission (FCC) of the United States of America, the Office of Communications (Ofcom) of the United Kingdom, and the Independent Communications Commission of South Africa (ICASA)) to promote efficient, effective and equitable use of RF spectrum. This is because it is widely understood that the RF spectrum can serve as platform for economic and social development [1]. At the global level, the regulation of RF spectrum is also supported by the International Telecommunications Union radiocommunications sector (ITU-R) constitution, which states that it is “the sovereign right of each State to regulate its telecommunication” [2].

It is worth noting that spectrum regulators have traditionally statically allocated a fixed portion of radio spectrum to each new radio-based service, (i.e. band-by-band, service-by-service) to such an extent that it is now becoming increasingly difficult to find usable radio spectrum to accommodate the rapidly expanding demand. This is furthermore validated in [3], a report by Motorola which indicates that demand for this non-depleting but limited precious resource will outstrip supply by the year 2015 due to the ever-growing number of spectrum-hungry mobile broadband applications [3].

This scarcity, however, is to a large extent caused by inefficiencies in conventional static spectrum management regulations. Studies have shown that spectrum scarcity is artificial because the actual spectrum utilisation on a block of licensed RF spectrum band was found to vary between 15% and 85% at different geographic locations over time [4, 5, 6].

The evolution of cellular communications in the past three decades has witnessed a tremendous increase in the demand for two-way mobile communication services globally. As per 2011 statistics, there were over 4 billion mobile users and 4.6 million radio base station sites worldwide [7]. Mobile and broadband traffic continues to grow at exponential rates prompting further investment in network capacity, requirements for new spectrum and advanced air interfaces, which can provide improved energy and spectral efficiency. Commensurately, energy or spectrum use and costs continue to rise compelling the need for future networks to be designed with energy usage that does not increase at the same growth rate as the traffic running over the networks. Although information and communications technology (ICT) can contribute to enabling a low carbon economy, the energy and carbon impact of the sector itself is significant [8].

Advances in radio access technologies allows RF spectrum to be dynamically accessed in time, frequency and space. This helps to improve the overall spectral utilisation efficiency through sharing [9]. These promising technologies have also helped to change our perception of how spectrum should be managed, particularly with regard to the impending scarcity, by calling for new flexible spectrum management policies. The main recommendations of this paper are:

- An incentive-based policy approach by the regulator to telecommunications operators to adopt the use of green radio technologies.
- The importance of bridging the digital divide in rural areas by combining DSA-based radio technologies and license-exempt policies in designated bands.

The rest of this paper is arranged as follows. In Section II we explain existing radio spectrum management approaches. We then describe the environmental impact of ICT industry in Section III. We go on to explore dynamic spectrum regulations and standards in Section IV. In Section V, we highlight the new perspectives of DSA policies. We conclude this paper in Section VI.

II. Conventional Radio Spectrum Management Approaches

Under most conventional static and centralized spectrum management approaches, national spectrum regulatory agencies generally determine which application/service and which transmission standard must be used in each licensed block of spectrum. An alternative approach is to allow market forces to influence decisions on spectrum usage wherever possible within a licensed spectrum management framework [10]. In this section, we discuss conventional RF spectrum regulation approaches that have been used over the past decades.

A. Command and Control Approach

In the command and control (C&C) approach, an RF spectrum license is issued for a limited time, subject to regular renewals. A license-holder is restricted to deploying only the prescribed radio-based services and technologies, as well as to comply with site and device standards (e.g., terrestrial television broadcasting) [11].

B. Property Rights Approach

This is a license-based approach which offers exclusivity, that is a license-holder is free to deploy any radio-based service and technology of their choice in the given geographical license area. Additionally, this approach opens an avenue for primary user (PU)-secondary user (SU) and co-primary users RF-spectrum sharing scenarios, as well as the prospect of secondary spectrum trading [12]. For example, spectrum access rights can temporarily be transferred to a secondary user for an agreed form of payment.

C. Spectrum Commons Approach

In this approach, users share the specified license-exempt RF spectrum bands, (e.g. the Industrial, Scientific and Medical (ISM) band). However, they are required to adhere to pre-set specified minimal operating conditions such as a maximum transmitting powers.

The rule of coexistence is among major drawbacks of the spectrum commons approach. The rule of coexistence may limit the kind of technology that can be deployed. Currently there are no limitations on the number of devices sharing the spectrum. This lack of limitations frequently degrades the quality of service (QoS) available to the network's users (a problem known as the Tragedy of Commons) [13].

III. Towards Green Radio Policies

The findings in [14] show that in the year 2007, the ICT sector was responsible for up to 3% of global total energy consumption, and 2% of its carbon dioxide (CO_2) emissions. The main challenge has been on how to allow the rapid growth of ICT sector while reducing energy consumption and CO_2 emissions.

A common ICT foot printing methodology framework across all ICT industries is anticipated to support the calculation, monitoring and reduction of ICT-related emissions globally. The overarching goal is to reach consensus within the global ICT sector on a common methodological framework for the measurement of energy consumption and carbon emissions arising from the production, and operation of ICT goods, networks and services [14]. According to one estimate the growth of the ICT footprint will less than double between 2007 and 2020, whereas that of mobile communications will nearly triple in the same period [15]. Therefore, there is an urgent need to improve the energy efficiency of cellular mobile systems and other wireless networks.

Energy detection is the most popular spectrum sensing method used to detect the presence of other users in an RF spectrum band of interest. This method has the following advantages and disadvantages [16]:

- **Advantages:** It is the most popular method because of its greater detection speed and its lower computational complexity compared to cyclostationary feature analysis.
- **Disadvantages:** Regulators such as the FCC and Ofcom does not consider spectrum sensing alone as a sufficiently reliable method of detecting PUs in particular bands of interest due to multipath and shadow fading effects.

New energy-efficient networks are one of the ways to cut down the amount of energy consumption per bit transmitted, manage ICT equipment more efficiently and conserve natural energy sources. However, the integration of local renewable energy sources represents a major technical challenge.

Ofcom showed interest in the CO_2 footprint by commissioning a comprehensive report analysing the UK greenhouse gas emissions by end-users in 2010. This report gives the percentage of CO_2 emissions in various end user sectors such as business, transport, domestic, agriculture and transport [17]. The EU's 2010 telecommunications industry reform legislation created a body of European regulators for electronic communications (BEREC) to study trends and developments in energy-efficiency in the areas of M441 (development of an open architecture for utility meters) and M462 (enabling efficient energy use in fixed and mobile information and communication networks).

China's ICT industry contribution to reduced CO_2 emissions is provided in [18]. In 2008 it was estimated that direct CO_2 emissions savings from low carbon telecommunication solutions provided by China Mobile (the largest mobile operator in China) stood at 48.5 million tonnes or just over six times the company's own emissions. While in 2009, the savings increased to approximately six and a half times the company's emissions. The regulation considerations target a minimum of 600 million tonnes of CO_2 emissions reductions from ICT solutions in four areas

Table 1: *A summary SWOT analysis of green radio policies.*

Method vs. Indicator	Strengths	Weaknesses	Opportunities	Threats
Green radio compliance strategies	▪ Some regulators, telecommunications operators and standardization bodies around the world have started to embrace the concept of green communication networks.	▪ Insufficient manufacturing process, operational process and ICT usage energy efficiency.	▪ Use smart technologies to maintain the same number of BSs even when the number of subscribers is increasing. ▪ Use of alternative energy sources. ▪ Use of energy scavenging techniques to support small sized devices. ▪ Reduce power consumption at data centres and cloud services through virtualisation techniques.	▪ Non-compliance or late adoption of green radio compliance strategies means more pollution to the environment.
Green radio compliance incentives	▪ Helps to promote a quick adoption of green radio technologies.	▪ A relatively new concept not widely tried and tested.	▪ ICASA and other African regulators should promote green compliance incentive policies to operators as well as users.	▪ Possible resistance from operators due to costs concerns.
Green environment policy	▪ The UN has series of climate change conferences (such as COP17/CMP7).	▪ Most of telecommunications regulators particularly in the African continent are subjected to political interference.	▪ ICASA and industry stakeholders can develop green compliance policy along with the spectrum policy	▪ Similar bodies across the globe are competing

(smart logistics, dematerialisation, smart work and smart appliances) by 2020 and 1,000 million tonnes by 2030.

The Communications Commission of Kenya (CCK) is the spectrum regulatory state corporation in Kenya established in 1999. The CCK creates guidelines on the rollout of communication network infrastructure. According to a presentation by Njiraini [19] the CCK established an ICT policy in the year 2006 that is cognizant of e-waste. The provision states that as a prerequisite for the granting or renewal of spectrum licenses, applications must demonstrate their readiness to minimise the effects of their infrastructure on the environment.

The FCC has proposed a collaboration framework with the US Department of Energy to understand the communication, security and privacy-related requirements of electric utilities so that FCC can advise appropriately on federal smart grid policies and governmental departments on improving the energy-efficiency of their data centres [20]. Table 1 presents a SWOT analysis on green radio policies.

IV. Dynamic RF spectrum Regulations and Standards

Most dynamic spectrum access (DSA)-based standardization and regulatory efforts have focused on the issue of how to protect PUs from possible harmful interference that might be caused by SUs. However, this does not mean that SUs are not considered to be as important as PUs. To a large extent, this is attributable to the fact that one must first have un-used RF spectrum in the spatial or temporal dimensions before considering DSA technologies. Additionally, according to Weiss [21] most PUs' devices, services, and applications are already well standardized and regulated while SUs' are not because such technologies are still considered emerging. A discussion of DSA from the standardization and regulatory perspectives is provided in the following sub-sections.

A. Dynamic Spectrum Access Regulations

A fundamental step towards the successful introduction of dynamic RF spectrum sharing is for a regulator to unambiguously re-define usage rights for each player (i.e. PUs and SUs) in each usage scenario. One example in that particular direction is Ofcom's introduction of a regime known as Special Usage Rights (SURs). In this regime, the rights of a license holder are defined in terms of the maximum levels of interference they can cause others rather than the maximum power levels that they are allowed to transmit. By reciprocity, license holders can also determine the interference that they can expect from their neighbours [22, 23].

That step however, goes hand-in-hand with enabling technical standards for DSA. The Institute of Electrical and Electronic Engineers (IEEE) 802.18 radio regulatory technical advisory group (RR-TAG) [24] is one initiative towards this goal. Its main objective is to act as an intermediary to the ITU-R, national spectrum regulators and other stakeholders that are dealing with regulatory issues particularly those based on the 802 families of wireless technologies.

Globally, the ITU-R through the recent World Radio Conference 2012 (WRC 12) produced its final recommendations for possible deployment of DSA-based technologies in TV bands, although spectrum regulations are done on a national basis [25]. On a national level, the USA's FCC and the National Telecommunications and Information Administration (NTIA) have continued to spearhead the adoption of much more efficient and flexible radio spectrum regulations. The two bodies have proposed and developed several guidelines and regulations on how DSA technologies can be used to exploit both government and commercial/civilian spectrum in co-primary sharing and PU-SU sharing scenarios.

The new regulations include allowing unlicensed operations in the 5 GHz band using dynamic frequency selection (DFS) techniques and allowing shared licensed operations in the 3.65-3.7 GHz bands using contention-based protocols. However, the most notable innovation in this regard is the rule allowing unlicensed operations in the digital dividend (the term used to describe the freed-up spectrum after migration from analogue to digital terrestrial TV broadcast) and in the un-used television channels in space, time and frequency. These un-used TV channels are also known as television white spaces (TVWS). TVWS in the very high frequency (VHF) and ultra high frequency (UHF) bands have superior propagation characteristics with improved line of sight (LoS) coverage, non-line of sight (NLoS) coverage, geographical coverage, penetration of buildings, natural obstacles, and foliage. This makes TVWS particularly suitable for providing wireless broadband in rural areas. Initially, the mandatory protection mechanism for PUs is for SUs to access TVWS using spectrum sensing techniques and a combination of geo-location and access to a database that containing real-time lists of fallow TV channels.

Moreover, in a recent FCC ruling [26], the requirement to use spectrum sensing was relaxed for white spaces devices (WSDs) that use a combination of geo-location and database lookup functions. The FCC has so far designated nine companies as geo-location database administrators. Furthermore, the FCC has been instrumental in encouraging RF spectrum to be traded in secondary markets using various dimensions such as time, space and frequency [27]. In the wake of its decision, the FCC has recently passed a landmark regulation to allow innovative sharing of TV broadcast channels among broadcasters [28]. A complementary regulation to allow incentive auctions (perceived as a legal instrument to encourage TV broadcasters to trade their un-used spectrum) has also been proposed [29].

Ofcom is also working towards the implementation of license-exempt dynamic access in the digital dividend [30, 31]. The proposed PU protection techniques are similar to the ones mandated by the FCC. Other spectrum regulators in the European Union (EU) are at various stages of regulatory reforms towards the implementation of cognitive access technologies in TVWS and the digital dividend [32]. Most of the pioneering DSA regulatory and standardization activities in the Asia-Pacific region come from the Info-communications Development Authority (IDA), Singapore's spectrum regulator. For the past two years, IDA has been involved in local and international WSD trials and it is now almost certain to authorize their use in Singapore [33]. It is worth noting that most countries in the developing world including Africa are still lagging behind on the regulatory front pertaining to possible deployment approaches for DSA-CR technologies. To the best of our knowledge, the Information and Communication Technologies Authority (ICTA) of Mauritius is the only African regulator with a clear DSA policy [34, 35].

B. *Dynamic Spectrum Access Standards*

Many standards are being proposed and developed by different bodies for the DSA-based technologies [36]. Some of the standards that are of interest in the context of this paper include: (Note all IEEE standards are defined in [39]):

ETSI reconfigurable radio systems (RRS) [37]: ETSI considers the feasibility of possible operations of the long-term evolution (LTE) standard in the UHF 470-790 MHz frequency bands over TVWS. In many cases, it is assumed that TVWS would be largely available in rural areas where broadband connectivity is rarely available. The LTE time division duplex (TDD) mode is considered to be a suitable candidate for SU operations over TVWS in rural areas rather than the LTE frequency division duplex (FDD) mode. This is because first, it utilises un-paired spectrum band that is traditionally cheaper, and secondly, it does not require duplexing equipment thus lowering overall infrastructure cost and ultimately lowering the cost of services.

European Computer Manufacturers Association (ECMA)-392 [38]: The main objective of this standard is to facilitate low-power home and portable devices to operate over TVWS in the UHF band. The standard is jointly developed by the cognitive network alliance (CogNea) and ECMA international.

IEEE 802.22 standard for wireless regional area networks (WRANs): This standard focuses on rural broadband wireless access. The key objective of the standard is to re-use TVWS without causing any harmful interference to PUs (i.e., the TV broadcasting station transmitters). This is achieved by the application of DSA-CR techniques. This standard is designed to operate in the UHF and VHF over TVWS ranging from 54 to 862 MHz.

IEEE 802.11af: This standard is also known as White-fi. It is expected to extend the traditional Wi-Fi (802.11) to TVWS. A system based on IEEE 802.11af can be described as a wireless network with DSA and cognitive radio (CR) enabled access points (APs) operating over TVWS via spectrum sharing mechanisms.

IEEE 802.11y: The main objective of this standard is to allow high-power co-primary and secondary Wi-Fi-like operations in the 5 GHz radar and the 3.65-3.7 GHz Earth satellite bands. It is envisaged that the RF spectrum sharing in such systems is to be facilitated through well-known contention-based protocols (CBP) and DFS.

802.16h: This standard enables co-existence among licence-exempt systems based on 802.16 standards (also known as WiMAX.) Furthermore, this standard facilitates the co-existence of the afore-mentioned systems with licensed systems (PUs). Such co-existence is facilitated through the application of CR techniques in two distinct models: coordinated co-existence (CX) and un-coordinated co-existence (UCP).

IEEE 802.19: The main objective of this standard is to enable the family of IEEE 802 wireless networks to most effectively use TVWS by providing standard coexistence mechanisms among dissimilar or independently operated TVWS networks and dissimilar TVWS devices. More broadly, this standard addresses the issue of coexistence between unlicensed 802-based wireless networks. A SWOT analysis of DSA standards is presented in Table 2.

V. DYNAMIC SPECTRUM ACCESS: NEW PERSPECTIVES

In this section we discuss new perspectives on green radio and rural connectivity relating to dynamic spectrum access.

A. *Incentives for Green Radio Policies*

Regulators should adopt policies that incentivise telecommunications operators to utilise energy efficient/environmentally friendly radio technologies to mitigate the negative impacts of climate change. One possible approach could be for spectrum regulators to introduce a green-based merit point policy to the wireless-

Table 2: *A summary SWOT analysis of DSA standards.*

Initiative	Strengths	Weaknesses	Opportunities	Threats (Standards)
ETSI RRS (LTE-FDD)	▪ Higher mobility ▪ Large cell sizes (5-100 km) ▪ High data rates ▪ Utilises paired and un-paired spectrum ▪ Utilises digital dividend	▪ Possible resistance from license holders	▪ Consumer-class urban/remote/rural mobile broadband	802.22 WRAN
ECMA-392	▪ High data rates ▪ Utilizes TVWS	▪ No mobility ▪ Secondary user is unprotected ▪ Possible resistance from license holders	▪ Consumer-class personal/portable/in-home multi-media networking	Ultra-wide band (UWB)
802.22 WRAN	▪ Large cell sizes (30-100 km) ▪ High data rates ▪ Utilises TVWS	▪ No mobility ▪ Secondary user is unprotected ▪ Possible resistance from license holders	▪ Consumer-class fixed remote/rural wireless broadband	ETSI RRS (LTE-FDD)
802.11y	▪ Medium/long range AP coverage (up to 5 km) ▪ Utilises radar band ▪ Utilises Earth satellite bands	▪ Low mobility ▪ Secondary user is unprotected ▪ Possible resistance from license holders	▪ Enterprise-class metro fixed wireless broadband	802.11af 802.16d
802.16h	▪ Enables seamless operation among 802.16-based systems	▪ Doesn't really address non-802.16 -based systems	▪ Enterprise/consumer classes-fixed wireless systems	802.21 MIH 802.19
802.19	▪ Enables seamless operation across IEEE 802-based wireless networks and devices	▪ Doesn't really address non-IEEE 802-based fixed and wireless networks and devices	▪ Enterprise and consumer classes wireless networks and devices	802.21 MIH 802.16h

operators (similar to carbon trading schemes). Attaching optional green networking requirements to new spectrum license applications, or renewals could be one among possible methods to do this. Similar requirements could be applied to operation in license-exempt spectrum bands. The requirements in this green-based merit point policy could be drawn from two critical areas where most of the CO_2 emissions and energy consumption in telecommunications emanate from:

1. Manufacturing processes of telecommunications equipment. It should be clearly established if the operator uses refurbished or new equipment (refurbished equipment is regarded to be more "green" than new equipment.) If new equipment is used, it should be established how much energy was used during the manufacturing process. This could be checked through various means such as green compliance certificates).
2. Data centres hosting telecommunication operators' servers. It should be determined how energy efficient third party or in house data centres in use actually are.

In return, the regulator should award the compliant operators with green merit points, the accumulation of which could later be exchanged for more favourable licensing conditions such as reduced spectrum licensing fees or first preference in spectrum license issuing processes.

B. Improved Spectrum Access in Rural Areas to Bridge the Digital Divide

The need to bridge the digital divide in under-served remote and rural areas cannot be over emphasized. In [40], it has been shown that low spectrum utilization, particularly in rural areas is inseparable from, and directly pertinent, to the digital divide. Consequently, spectrum regulators from developing countries in particular, should emulate the policy initiatives taken by the FCC to bridge the digital divide by encouraging telecommunications operators to provide low-cost, long-range wireless broadband connectivity in rural areas. This could be achieved by allowing innovative opportunistic access (using DSA-based technologies) in specified portions of the RF spectrum such as the digital dividend and TVWS in the VHF and UHF bands on a license-exempt basis.

VI. Conclusion

The on-going changes introduced by next generation wireless technologies calls for spectrum regulators around the world to come up with new regulatory policy approaches. With growing concerns about looming RF spectrum scarcity, environmental sustainability and the digital divide, there are on-going efforts from governments, regulators, standardization bodies, industry and academia to search for and promote energy efficient, environmentally friendly green radio technologies and policies. In this paper, we discussed conventional and emerging dynamic spectrum regulatory regimes and standards used by regulators around the world. Furthermore, we highlighted the growing environmental impact caused by the ICT sector. Finally, we recommended an incentive-based green policy approach to encourage telecommunication operators to deploy environmentally friendly networks and devices, and highlighted the importance of bridging the digital divide in the rural areas by combining DSA-based radio technologies and license-exempt policies in designated bands.

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