Valuation and Pricing Of Licensed Shared Access: Next Generation Pricing for Next Generation Spectrum Access

Gérard Pogorel, *Professor, Telecom ParisTech*, Erik Bohlin, *Professor, Chalmers University*

Abstract— The paper proposes a first attempt at valuation and pricing principles for LSA/ASA within the forthcoming regulatory framework and assignment.[1]

Index Terms— Licensed shared access, Radio Spectrum, Spectrum valuation, Spectrum pricing

PRELIMINARY VERSION 30/06/2014

I. Introduction

DEMAND for access to the radio spectrum is constantly and rapidly growing. In particular, more radio spectrum is needed to cope with a tremendous growth of wireless data traffic volume [1] generated by smartphones, tablets, and other mobile devices [2]. According to a recent forecast, global mobile data traffic is expected to increase nearly 11-fold between 2013 and 2018. With a compound annual growth rate (CAGR) of 61 percent, it will reach 15.9 Exabyte per month by 2018, compared to 820 petabytes per month at the end of 2012. Consumer demand is oriented towards spectrum-hungry applications and services, such as video. Over two-thirds (69 percent) of global mobile data traffic will be video by 2018, registering a 14-fold increase between 2013 and 2018. Along with data traffic volume, device penetration is dramatically increasing. By the end of 2014, the number of mobile-connected devices will exceed the world's population, and there will be over 10 billion mobile-connected devices by 2018**.** The growing need of wireless connectivity is due to not only wireless broadband but also machine-to-machine (M2M) communications**.** By 2018, there will be 2 billion machine-to-machine connections (e.g., GPS systems in cars, asset tracking systems in shipping and manufacturing sectors, medical applications, etc.) [3].

As matters stand, a spectrum crunch might occur, as there is no sufficient available spectrum to meet the future needs of wireless networks. This is quite a paradox given that sizeable portions of assigned spectrum turn out to be not fully utilised in certain geographical areas or points in time [4]. Indeed, the current spectrum policy framework goes mostly in the direction of exclusive rights of use, with only limited provision for shared spectrum. This orientation lies at the origin of large portions of spectrum being underutilised by incumbent users [6] [5] [6]. Exclusive assignment of frequency bands has been an effective way of managing radio spectrum, until the increasing density of wireless services has threatened the effectiveness of existing policies as means of protecting from harmful interference without jeopardizing efficient spectrum use [7]. The lack of sufficient spectrum to face the growing spectrum demand is due to not only quantity but also quality of available spectrum. High data rate services require wide spectrum bands, which also need to be available on predictable terms in order to ensure a guaranteed

[1] The authors express their gratitude to Qualcomm Inc. for having supported this research. They take sole responsibility, however, for the choice of this topic, the methodology and conclusions of the research. In particular, Qualcomm Inc. is evidently not involved in our appraisal of the economic and financial phenomena of the past decade that serve as a background to our proposals and recommendations.

G. Pogorel, Professor of Economics and Management, is with Telecom ParisTech Graduate School of Telecom Engineering, Paris, France (e-mail: gerard.pogorel@telecom-paristech.fr).

E. Bohlin, Professor of Technology Management and Economics, is with the Div. of Technology & Society, Chalmers University of Technology, Göteborg, Sweden (e-mail: erik.bohlin@chalmers.edu).

The authors thank Ms Maria Massaro, Doctoral candidate at Chalmers University, for her contributions to the research and for establishing the bibliography.

Quality of Service (QoS) [4]. The current environment characterised by fast changes in technology and market conditions requires existing outdated practices to back off, enlarge our perspectives, and leave space for more dynamic spectrum rules.

In the cases where incumbents use the assigned spectrum only in a specific geographic area and/or at certain times, it raises the possibility for other users to access the same spectrum, on a shared basis, in other geographic areas and/or at other times, respectively [2]. In international arenas, new and more robust forms of shared access to already available but not fully utilised spectrum have been generally recognised as a timely and effective tool to make more spectrum available. The shared use of spectrum refers to situations in which a number of independent users share given frequencies under certain conditions [8]. Clear conditions need to be established in order to assure the collective radio spectrum use by existing and new users without disrupting one another.

In Europe, for instance, finding possible spectrum-sharing opportunities is one of the goals pursued by the Radio Spectrum Policy Programme (RSPP) by means of the spectrum inventory process [9]. In 2011, the Radio Spectrum Policy Group (RSPG) published an Opinion on cognitive technologies, highlighting the importance of intelligent technologies to share radio frequencies [10]. In the same year, it published a report bringing forward a dynamic approach to spectrum sharing. Moreover, the European Commission (EC) Communication COM(2012) 478 on "Promoting the shared use of radio spectrum resources in the internal market" recognised the shared access to spectrum as the solution at the forefront to the problem of lack of available spectrum for new spectrum needs [11]. Recently, the EC issued a mandate to CEPT to study the possibility of shared spectrum use between wireless broadband services and incumbent uses in the 2.3 GHz band [12].

In the United States, the idea of spectrum sharing has been extensively discussed since 2006, when the National Telecommunications and Information Administration (NTIA), in coordination with the Federal Communications Commission (FCC), examined the feasibility of spectrum sharing between federal and non-federal users [4]. In 2013, the FCC took steps to promote a more efficient use of radio spectrum, proposing to use the 3550-3650 MHz band, currently utilised for military and satellite operations, for providing broadband services by implementing small cells and spectrum sharing techniques [13].

II. Next Generation Spectrum Valuation and Pricing for Next Generation Spectrum Access

Considering the new set of technical and economic conditions, it does not seem excessive to think we enter a new generation of spectrum access formulas, with corresponding spectrum valuation and pricing methods. A first generation of policy [14] was characterized by exclusive allocation of each frequency band to single use and typically a single licensed user, and assignment by administrative procedures. The past twenty years have seen the emergence of a second generation of spectrum policies characterized by a trend towards market mechanisms (auctions and secondary markets). It is to be noted this trend in radio spectrum management took place in the context of "irrational exuberance" on financial markets, on the one hand, runaway government deficits and creative budgetary attempts at coping with it on the other. In parallel we have witnessed the limited extension of the usage of unlicensed access principally under the form of WiFi. It is now clear from the results on the ongoing assignment by auctions processes still at play in many countries, that the argument that auctions are the way to select the most determined and potentially the most efficient actors through a competitive process has lost the validity it might have had as the least evil. The limitations of market mechanisms as an efficient spectrum allocation tool, had been anticipated by [15] and [16]. There is a risk that spectrum auctions would tend to be considered as a routine way for incumbents to preserve the status quo, fend off new entrants and prevent potential disruptive innovations. In the new context, and in particular given the importance to be expected for shared spectrum, a new perspective is warranted.

For governments, coming up with new radio spectrum assignment processes, is part of the structural reforms that are called for to foster innovation and growth. To exit the vicious circle of deficits, debt addiction, always more taxes, and creative accounting, governments go through a painful rehab phase. Getting rid of spectrum auctions is part of it.

Mobile network operators (MNOs) have demonstrated outstanding competencies and dynamism in writing one of the most impressive sagas of the industrial age by making possible instant communication between 7 billion people. Their collective interest is for regulation to preserve the competitive conditions of innovation. The current period inaugurates a third phase, with far richer, possibly infinite potentialities for wireless services and technologies. The focus on exclusive use and assignment by auctions will progressively become less and less relevant. The radio spectrum is progressively seen, thanks to technology advances, as a pool to be jointly exploited by all users, present and future. This applies to the spectrum used by public entities. In this context, clearing spectrum from old to new uses will always be part of spectrum allocation dynamics, but sharing will be always more important, either as permanent or transitory. As stated in 2012 by the EU Commissioner [17] as well as recently by the FCC Chairman: “Big breakthrough policy – spectrum sharing » [18]. It seems to us it is worthwhile exploring what third generation allocation and assignment methods would best correspond to these potentialities.

III. Authorised Shared Access and next generation forms of spectrum access

A. Sharing modalities

Recent technological evolutions and innovations have the potential to increase efficiency in spectrum use, by enabling new forms of spectrum sharing [7]. Intelligent technologies, such as reconfigurable networks, coupled with frequency, location and time sharing conditions, allow a number of different users to coexist within the same frequency bands, through power and interference reduction techniques [4]. Reconfigurable Radio System (RRS) is a generic concept that refers to technologies such as Software Defined Radio (SDR) and Cognitive Radio (CR), whose systems are able to reconfigure their parameters, including frequency and power, in order to self-adapting to a dynamically-changing environment [19]. RRSs, combining radio equipment with software capable of analysing the radio environment and adjusting radio systems’ features, provide greater flexibility for an optimal shared use of spectrum [20].

In ITU-R Report SM.2152, SDR is defined as a “radio transmitter and/or receiver employing a technology that allows the RF operating parameters including, but not limited to, frequency range, modulation type, or output power to be set or altered by software, excluding changes to operating parameters which occur during the normal pre-installed and predetermined operation of a radio according to a system specification or standard” [21]. The use of SDR, often combined with Cognitive Radio (CR), is drawing increasing attention, as recent developments have lowered SDR equipment costs and lengthen SDR equipment lifetime [19].

There is particular interest worldwide for CR, defined as a “radio system employing technology that allows the system to obtain knowledge of its operational and geographical environment, established policies and its internal state; to dynamically and autonomously adjust its operational parameters and protocols according to its obtained knowledge in order to achieve predefined objectives; and to learn from the results obtained” [21]. Indeed, CR possesses learning capabilities, acquiring knowledge of the radio operational environment (in terms of available radio resources, prevailing spectrum rules, user needs and preferences, operational costs of a service, etc.) and the ability of reconfiguration, adapting its operational parameters and protocols according to the acquired knowledge [10, 19]. CRs are capable of cognitive behaviour, which develops along a cognition cycle, articulated in six phases: “Observe, Orient, Plan, Learn, Decide, Act” [22].

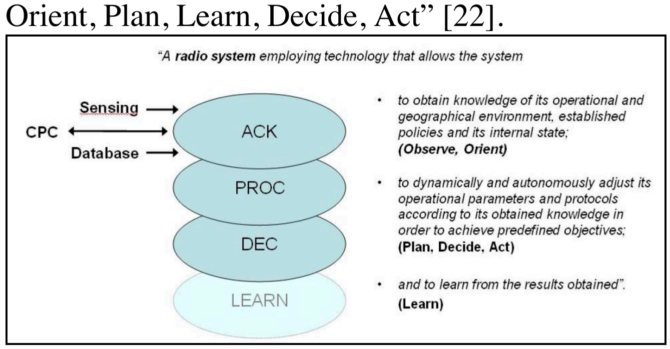


Figure 1: Representation of definition of cognitive radio
Source: RSPG Opinion on cognitive technologies [10]

CRs are provided with different functionalities, which ensure a more effective spectrum sharing. For instance, CRs are able to continuously scan and detect actual unused spectrum frequencies, which are then assumed to be usable. This function, called spectrum sensing, aims at enhancing spectrum usage efficiency by finding opportunities for spectrum access (in various dimensions: time, spatial and frequency), without interfering with incumbent users of the band and adjacent bands. Moreover, CRs are able to determine their own location and know the frequencies they can use in that exact location by querying a database that contains a list of assigned or available frequencies or predefined rights and obligations which are specified in terms of time and location [6]. Cognitive radios, however, despite years of research efforts, have not come up yet with widely applicable solutions. More attention is devoted presently to broader shared access concepts.

B. The LSA/ASA concsepts

New regulatory paradigms for spectrum authorisation are needed in addition to the classical exclusive assignments, to allow shared use of spectrum in a more flexible way, taking advantage of technology advances [1]. An authorisation scheme for spectrum rights of use, which is gradually attracting policy makers' attention, is named Authorised Shared Access (ASA) [4]. ASA was initially proposed by an industry consortium composed by Qualcomm and Nokia (Ingenious, 2010), with the aim of promoting the use of certain spectrum bands by International Mobile Telecommunications (IMT), whenever and wherever they are unused by incumbent users, while safeguarding existing usages and ensuring predictable quality of service [23]. The ASA concept has been extended to the notion of Licensed Shared Access (LSA) by the Radio Spectrum Policy Group RSPG, composed of representatives of Member states and the European Commission, assisting the Commission in the development of radio spectrum policy in the Community. It recognised several sharing opportunities, in addition to the case put forward by Qualcomm and Nokia [6]. The RSPG Opinion on LSA, approved in November 2013, defines the LSA concept as follows: "A regulatory approach aiming to facilitate the introduction of radio communication systems operated by a limited number of licensees under an individual licensing regime in a frequency band already assigned or expected to be assigned to one or more incumbent users. Under the Licensed Shared Access (LSA) approach, the additional users are authorised to use the spectrum (or part of the spectrum) in accordance with sharing rules included in their rights of use of spectrum, thereby allowing all the authorised users, including incumbents, to provide a certain Quality of Service (QoS)" [25]. The concept of ASA/LSA is based on the idea of licensed sharing spectrum. Frequency bands already assigned to existing spectrum users, might result underused. Thus, in order to access this underused spectrum, individual spectrum rights of use might be assigned to one or several new users. In this way, the spectrum holder under national frequency register would share spectrum with one or a limited number of LSA licensees, in accordance with a set of sharing arrangements imposed on both groups of users. The National Regulatory Authority (NRA) would have to define these sharing conditions in cooperation with all parties involved, taking into account interests of users in adjacent bands as well [26, 1]. Access to and evacuation of the band may be nearly real-time with LSA in some cases, giving a lot of flexibility in setting up the sharing conditions. LSA pursues the objective of increasing the controlled use of spectrum. It seeks a stable spectrum use by spectrum rights holders, so that predictability of the conditions of spectrum usage and of QoS for all spectrum users, network operators and consumers can be guaranteed. It is important to underlie that ASA/LSA does not challenge the existing regulatory framework for the use of spectrum, it rather complements it [1]. ASA/LSA does not have to be considered as an alternative to the current spectrum authorization schemes of exclusive licensed and license-exempt spectrum, but as a complementary regulatory approach to increase efficient spectrum utilization, by facilitating the introduction of new applications, through an individual licensing regime, while maintaining the existing ones [4, 6]. The exclusive feature of this model is the possibility of enabling faster access to spectrum bands, which can be used by new services together with incumbent users without causing interference, by applying intelligent technologies, such as those mentioned above [23]. The LSA model has been generally accepted as a fully-fledged alternative to other means of clearing spectrum, such as spectrum re-farming. This has become a more controversial, lengthy and time-consuming process over time [1], in particular in bands characterised by fragmented incumbent uses [23].

1) LSA/ASA in the spectrum landscape

Under the LSA concept, new users gain the access to already assigned but underused spectrum, which otherwise would not be available. Incumbent and new users share the same frequency bands by means of exclusive individual rights of spectrum, under predefined time and location conditions that govern their coexistence. The ASA/LSA concept is based on different principles than unlicensed spectrum access, spectrum access on a secondary basis or spectrum trading. In fact, it is applied when incumbent users, whose spectrum rights of use are not tradable, do not fully use their assigned spectrum, which can be shared in terms of time, geography and/or frequency with other users on a long-term basis [27]. The nature of incumbent users is not clearly stated: they might be both governmental entities and commercial (who have not obtained spectrum licenses through an award procedure – first come, first served; beauty contest; auction, for commercial use) operators. The application of ASA/LSA concept might occur when existing spectrum right holders are unable, for different reasons, or lack the incentives to make available unused spectrum frequencies. Non-commercial users might face regulatory constraints or lack appropriate incentive to give back unused spectrum, holding more spectrum than necessary, considering spectrum assignment as permanent and without costs. Commercial users may find uneconomical expanding spectrum utilization given the current institutional framework [4]. However, it is believed that the LSA model would be more functional if incumbents and LSA users belong to different categories (non commercial versus commercial), so that they are subject to different regulatory systems [2].

Studies are currently focused on the implementation of the LSA concept in the case of public service as incumbent usage, formulating sharing conditions with commercial uses, in particular mobile broadband. LSA offers a unique opportunity for MNOs and MVNOs to access additional spectrum, partially used for other incumbent uses, to complement their exclusive spectrum resources [1]. CEPT has been studying ASA concept since 2011. In October 2012, CEPT Working Group Frequency Management (CEPT WG FM) decided to study the applicability of LSA for Mobile and Fixed Communication Networks (MFCN) in the 2.3-2.4 GHz band, currently used by government use, such as military, Program Making and Special Event (PMSE) applications, and amateur services on a secondary basis, by establishing the Project Team FM52 [28]**.** Moreover, Project Team FM53 has been set up for general LSA related studies. The ECC Report 205 on LSA, which provides general analysis of LSA and guidance for CEPT in defining harmonisations measures, has been published in February 2014 [25].

2) LSA/ASA in public spectrum

The focus will be placed on LSA/ASA in public spectrum, as currently envisaged in the short term. LSA/ASA in commercial spectrum will be envisaged at this stage only as a secondary element, if necessitated for clarification purposes. In this paper, in the line indicated by the CEPT, the base case reference scenario will be the lease of the spectrum by player A (for instance Defence) to player B (MNO), by multiples of 5/10/20MHz (tech neutral IMT), with freedom to choose also geography, time or both. No sharing of infrastructure and sharing of maintenance costs are considered in this case for now, but this will have to be taken into account very soon in a second stage.

C. The economic benefits of ASA/LSA

A study conducted for the EC by SCF Associates Ltd shows that additional shared spectrum for wireless broadband could create significant net economic benefits for Europe. With an increase of between 200 to 400 MHz in shared access spectrum for wireless broadband, the European economy gains net benefits of the order of several hundred billion Euros by 2020 [11]**.** A key benefit for LSA licensees is the fast access to new spectrum, without waiting for difficult, costly and time-consuming re-farming policies, which could be immediately used for meeting growing spectrum demand [1].

In December 2013, Plum Consulting published a study including a cost-benefit analysis of the adoption of LSA in the 2.3 GHz band in Europe. It is estimated that making the spectrum available requires around €50 million plus administrative costs, compared to medium benefits of around €12 billion from savings in infrastructure costs (in net present values). The estimated value of cost savings ranges from €6.5 to €22 billion, up to €30 billion in the case of per-capita mobile data consumption reaching US level by 2018. In fact, MNOs can use this additional spectrum to provide capacity in urban areas at times of peak traffic demand which exceeds their network capacity, without incurring in additional infrastructure costs (as they rely on existing base stations sites), thus leading to lower prices for consumers. When governmental use is localised in rural areas, sharing spectrum is not likely to impact on the capacity required by MNOs. Instead, when governmental use requires national coverage or the band is used for PMSE services, MNOs might not have full availability of the band in the busy hour. If this scenario happens, a solution is to offload mobile traffic to other exclusive licensed bands or to rely upon WiFi complementary solutions.

In the case when MNOs do not face capacity constraints, MNOs may also decide to use this additional capacity to offer new service plans, for instance higher level of data consumption at cheap prices, generating benefits in the form of increased consumer surplus, which has been estimated to be around 2.3 billion Euros. Although the study conceives new service offerings possible from both existing MNOs and new entrants, the second case is considered unlikely in practical terms, due to extensive costs required to build new networks. Finally, the study highlights the fact that the amount of benefits that can be gained is considerable because of the ability to implement LSA concept in a short time period, meaning by 2015 [27].

The GSMA study proposes a comprehensive framework for spectrum valuation, in particular from the view point of MNOs, which is then applied to the 2.3 GHz band in Europe and the 3.5 GHz band in US. The economic impact of spectrum sharing depends of the probability that MNOs are willing to invest in shared spectrum. The maximum value is represented by the present value of the economic benefits related to the case of exclusive assignment. From this ceiling, the economic benefits that shared spectrum can provide are calculated by applying a number of impairment discounts which reflect the deterioration of sharing terms and conditions. According to this study, the main factors potentially reducing the MNOs likelihood of investment are the lack of harmonisation, meaning a minimum efficient scale of operation is needed; sharing dynamism, as the more the shared use of spectrum is dynamic the less control over spectrum operators can have; restrictions in term of geography, timing and network deployment conditions; and the contract length. According to this framework the adoption of the LSA in the 2.3 GHz band in Europe would generate up to €86 billion of incremental value added while the US adoption of LSA in the 3.5 GHz band would generate up to $260 billion in economic benefits [24].

The argument according to which shared spectrum is not appropriate for new entrants might be valid in the short-medium term. However, firstly it is a bit of a stretch for the 15-yearto infinite license durations that extend beyond our technology forecast capacity. Secondly, small cells technology can offer promising local and regional capabilities and ASA/LSA can provide openings for non vertically integrated MNOs, and telcos other than mobile.

D. Incentives to share

Spectrum management Efficiency

LSA offers a controlled environment where incumbent users can continue to offer their services, while sharing spectrum with other users**.** This is optimal in the case where the combined net socio-economic benefit of multiple applications sharing the band is greater than the net socio-economic benefit of a single application [2]. Thus, LSA would bring great benefits to enterprises, technology firms, governments, network providers, service providers and consumers in terms of more efficient use of spectrum, enabling timely access to spectrum for mobile broadband, which would not be available otherwise [1]. LSA would facilitate the implementation of standards, providing legal certainty and promoting economies of scale [2, 6]. In fact, it may favour the global harmonisation of spectrum allocated to IMT, which can be easily used on a shared basis with incumbents, while the allocation to IMT on an exclusive basis may be impractical [1].

E. Incentives for the parties involved

A fundamental prerequisite of the successful implementation of LSA is the acknowledgement of all parties involved in the sharing of spectrum.

1) Regulator

For the NRA, LSA contributes to fulfilling its duties to provide in a timely manner for the needs of public and commercial services. The NRA will have to conduct or endorse the LSA, in order to provide both the incumbent and the licensee with the same level of legal guarantee in the frequency usage.

LSA represents a strategic tool for regulators for allowing MNOs to timely access the spectrum in the case when incumbents will vacate frequency bands in the long term. LSA can be conceived not only as an alternative to exclusive assignment, but also as a temporary phase prior to spectrum re-farming [24] [26].

2) Incumbent

Initial spectrum right holders need to be protected, while LSA licensees benefit from access to unused spectrum, as the implementation of LSA might affect their rights of use [1]. For the incumbents, an incentive for engaging in a sharing arrangement would be financial of other forms of compensations (e.g. access to new services) from the LSA licensees [28].[2] In countries with a strong command and control or AIP legal apparatus, sharing an incumbent's frequency could result from an NRA decision pure and simple. As a rule, incentives to share for incumbents will have to be aligned with the valuation or non-valuation rules applicable to public spectrum in each country.

3) Licensee

From the LSA licensee's perspective, a key incentive is represented by the availability of spectrum, in a timely manner, for a sufficient period of time and in a certain geographic area [1]. Both incumbent users and LSA licensees require regulatory certainty over the conditions governing the shared use of spectrum. These sharing conditions should be sufficiently concise, attractive and predictable to incentivize LSA licensees to invest in equipment and network and existing users to allow spectrum shared use [2]. Part of the incentive, is that, as opposed to unlicensed, the sharing licensee is entitled to protection, which makes QoS achievable.

F. Candidate bands for sharing

Frequency bands, which have been identified for IMT by ITU, but have not been assigned yet for mobile services due to incumbent usage, are recognised as critical opportunities for sharing. Both the EU and US are engaged in developing sharing solutions in selected bands in their respective territories along with ITU initiatives [24]. Europe is focusing its attention on the 2.3 GHz band for the implementation of the LSA concept to open the band for mobile broadband services. 3GPP Band 40, the 2.3-2.4 band, has been allocated to the mobile service and identified globally for IMT as a result of the World Radio Communication Conference held in 2007 (WRC-07). Several countries, in particular in the Asia Pacific region, already committed to deploy mobile broadband networks in the 2.3-2.4 MHz band. Therefore, if we look at user equipment, as of June 2014, no less than 207 devices, including phones, mobile tablets, USB modems, from all major device manufacturers, as well as base station equipment are already available [57].. The related market cannot but grow in the coming years [12].

Within CEPT countries, the 2.3-2.4 MHz band is allocated to Fixed and Mobile on a primary basis and Radiolocation and amateur services on a secondary basis. However, the current situation of use is quite patchy. Principal incumbent uses are:

- Telemetry (both terrestrial and aeronautical telemetry)
- Other governmental use (e.g. Unmanned Aircraft Systems, UAS)
- PMSE (including SAB/SAP and ENG/OB);
- Amateur as a secondary service.

[2] Incumbents might look at LSA, as a means for lowering costs by releasing frequency bands to new users, whilst maintaining control over its use in the long term. It is worth clarifying that in the case of public services, the incentives for incumbents might be different, as usually fees are not applied to governmental entities. In this case the possibility of sharing costs of investments and maintenance of the infrastructure with new LSA licensees might be seen as a form of incentive [2].

As CEPT countries use this band in different ways, while some of them have already planned to release the 2.3-2.4 MHz band for mobile broadband services and proceed to exclusive licensing, in a number of other CEPT countries clearing the 2.3-2.4 MHz band would be quite difficult due to extensive incumbent usage. As things stand, LSA regime is assessed as the complementary regulatory measure which can ensure long term incumbent use, while enabling the availability of the band for mobile broadband services, in a timely manner [29].

CEPT has been studying LSA concept since 2011. In October 2012, CEPT Working Group Frequency Management (CEPT WG FM) decided to study the applicability of LSA for Mobile and Fixed Communication Networks (MFCN) in the 2.3-2.4 GHz band by establishing the WG FM Project Team FM52 [28]. Moreover, WG FM Project Team FM53 has been set up for general LSA related studies. The ECC Report 205 on LSA, which provides general analysis of LSA and guidance for CEPT in defining harmonisations measures, has been published in February 2014 [25]. Project Team FM52 has recently released the Draft ECC Decision on harmonising implementation measures for MFCN (including broadband wireless systems) in the 2.3-2.4 MHz band, which is planned to be finalised in June-July 2014 [30]. Moreover, in April 2014, the European Commission placed a mandate to CEPT to develop technical conditions for the introduction of wireless broadband services in the 2.3-2.4 MHz band [12].

France and Finland have actually simulated the implementation of the LSA concept in the 2.3-2.4 MHz band, mainly used for aeronautical telemetry and PMSE, respectively. In 2012, France did the first simulation in order to assess the impact of LTE networks on aeronautical telemetry (while the impact of aeronautical telemetry on LTE was not analysed). France concluded asserting the suitability of LSA as a potential solution to open the 2.3-2.4 MHz band to mobile services [31]. Later on, other compatibility studies followed, to test both the impact of aeronautical telemetry on mobile service and vice versa. For this purpose, a working group was established in January 2013 and coordinated by ANFR (Agence Nationale des Fréquences). All the main stakeholders have been involved with the aim to set up a sharing framework, which could ensure accessibility to the mobile service while maintaining incumbent usage [32]. Similarly, a field trial of the LSA concept using a TD-LTE network in the 2.3-2.4 GHz band has been implemented in Finland in 2013. It successfully demonstrated how a mobile network operator (MNO) can share spectrum with PMSE service, including cordless cameras, without causing harmful interference, as TD-LTE network is able to use the band and then vacate it when requested by the incumbent spectrum user [33].

In the US, the prominent candidate band for sharing is the 3.5 GHz (3550 – 3650 MHz) band. The range of frequencies comprised between 3.4 GHz and 3.5 GHz was identified for IMT in much of ITU Region 1 and in 8 areas within ITU Region 3. In ITU Region 2 (which comprises US), the 3.5-3.7 GHz band is allocated to the Fixed, Fixed Satellite (space-to-Earth), and Mobile (except aeronautical mobile) Services on a primary basis, and to Radio Location Services (RLS) on a secondary basis. On a domestic level, the 3.5 GHz band is allocated to RLS and the ground-based Aeronautical Radio Navigation Service (ARNS) on a primary basis for federal use and to federal non-military RLS use on a secondary basis. The 3.6-3.65 GHz band is also allocated to Fixed Satellite Service (FSS) earth stations. The 3.5 MHz band was identified for shared federal and non-federal use in 2010 by the National Telecommunications and Information Administration (NTIA) because current incumbent uses are mainly localised around the coasts and this offers great sharing opportunities to meet the increasing demand for spectrum. Thus, in July 2012 the President's Council of Advisors on Science and Technology (PCAST) recommended the sharing use of federal spectrum to increase spectrum access for non-federal uses [34] and in the same year the Federal Communications Committee (FCC) proposed to implement a three-tier system of spectrum access to manage the shared use of the 3.5 GHz band by small cells, while protecting existing incumbent users [13]. The proposal envisages implementing Spectrum Access System (SAS), which resembles the LSA architecture, although with some differences [35].

IV. Framework for ASA/LSA valuation and pricing

In this section we aim to contribute to the broad debate on next generation spectrum access by bringing our general considerations on LSA valuation and pricing. It is noteworthy that our purpose is to explore comprehensive valuation and pricing principles for LSA, without just focusing on valuation and pricing of "opportunistic" access (SDR, cognitive radios, etc.) and fast real time sharing ("spot").

The exponential growth of spectrum demand is leading to the development of numerous spectrum sharing models in regulation and research fields to improve efficiency and flexibility in spectrum use. Broadly speaking, three categories can be distinguished on the basis of the degree of exclusivity in the allocation of radio frequencies to different users.

At one extreme of the range, allocation schemes are close to exclusive use, with clear geographic limitations and time restrictions. At the opposite extreme, licence-free or unlicensed users obtain general authorisations to use certain spectrum bands under defined common rules, without any protection from harmful interference. Dynamic sharing approaches which combine intelligent technologies, and frequency, location and time sharing conditions, stay in the middle.

The first category has been object to extensive discussions regarding spectrum valuation and assignment, which mainly involve administrative pricing, benchmark approaches and auctions. Unlicensed spectrum models are usually meant to be free of charge, given the absence of control mechanisms other than transmitter power limitation. On the contrary, the middle ground has been subject to detailed technical considerations, without however proper assignment and valuation considerations. Thus, the following sub-section focuses on the regulatory valuation framework of sharing models developed in EU which belong to this category.

A. Regulatory valuation framework

It is important to mention that EU has been studying two possible dynamic sharing approaches: Collective Use of Spectrum (CUS) and Licensed Shared Access (LSA).

RSPG defines CUS as follows: "Collective Use of Spectrum allows an unlimited number of independent users and/or devices to access spectrum in the same range of designated CUS frequencies at the same time and in a particular geographic area under a well-defined set of conditions". CUS is actually applied to frequencies below 1 GHz, with different conditions. Generally, there is no exclusive access to spectrum and no protection from other authorised users operating in the same frequencies. A predictable level of QoS for users cannot be guaranteed, as it depends on the level of congestion, among other things. However it is believed this approach can be refined thanks to technology advancements [26].

Recently, much more attention has been focused on LSA. In the following, the main elements found in RSPG opinion on LSA and CEPT ECC report on LSA are summarised.

The key objective of LSA is to promote the shared use of spectrum between a limited number of licensed users. Thus, it should be clear that LSA users would use the spectrum under individual authorisations, while incumbent users keep using the assigned spectrum [1]. Hence the focus is only on "binary sharing" where the incumbent is not competing on the same downstream market as service provider sharer.

NRA is responsible for the assignment procedure of LSA rights of use, which should include specific technical and operational requirements (e.g. coordination process; compatibility criteria; conditions of the license – such as limitations in terms of timing and location; spectrum mask; etc.) [2] for an efficient shared use of spectrum. It must take into account national policy objectives, along with international obligations and European requirements, in the case of EU member states [23]. The NRA develops these sharing rules cooperating with all the parties involved [23]. In fact, LSA is a voluntary based approach: the sharing terms and conditions are to be agreed between the incumbents, the new users and NRA [27].

Under the LSA regime, non-interference principle is coupled with QoS/predictability of use. It must be assured no harmful interference to the incumbents, predictable QoS on LSA spectrum, and legal certainty to both incumbents and LSA licensees [27]. Incumbents must be sure that licensees will operate without causing restrictions when they are exercising their rights of use [1]. However, acceptable level of interference can be mitigated through reliable sharing arrangements. Incumbents may incur in costs due to implementation of improved technologies necessary to ensure good quality of services for new users. In this case, financial compensations should be agreed between the parties, as well as in the case when incumbents are subject to spectrum pricing [10, 2]. Moreover, if fees are paid by the incumbent user, which include elements of frequency time, location, this should be reflected in the pricing for the sharing user [2].

Likewise, it needs to be ensured that LSA licensees are able to offer services with a predicable level of QoS, otherwise they will not be incentivised to invest in shared spectrum [24].

Moreover, in compliance with the EU Regulatory Framework for electronic communications, in particular with the Authorisation Directive (Directive 2002/20/EC), the procedure for the assignment of LSA licenses must be done in a fair, transparent and objective manner [2]. Incumbents should also act in a transparent and non-discriminatory way in the definition of LSA requirements. For their part, LSA users should not obstruct the long-term innovation process held by the incumbents. In conclusion, fair competition and consumers' interest should always be guaranteed in the implementation of LSA [2].

B. *Technical and economic valuation parameters*

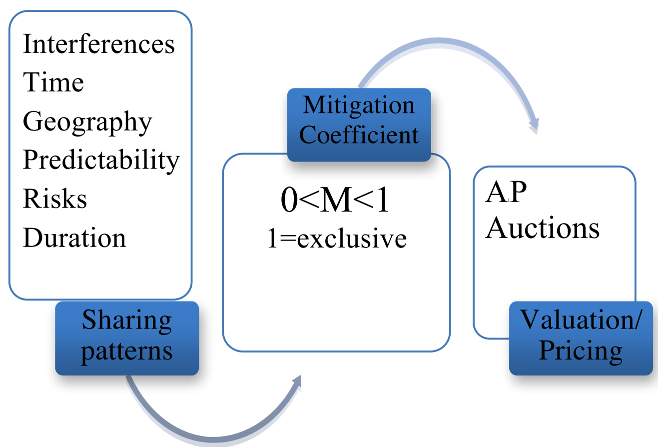
Valuation of shared spectrum cannot purely be based on considerations of interference level acceptance or mitigation, as exposed in [36].

LSA/ASA does not have the same parameters as exclusive use. On the minus side, sharing terms and conditions, such as time and geography limitations, impair the economic benefits of shared spectrum. Moreover, these limitations can be either permanent or planned in a predictable way, or, on the contrary, un-planned, meaning subject to the unpredictable needs of the incumbent. On the plus side, there can be no coverage or deployment obligations (population or territory), or no duty of continuity of services or universal service.

Once we leave the well-known areas of long-term exclusive use, what spaces do we encounter that keep a realistic flavour make business sense. The valuation/pricing of shared spectrum will reflect differences with exclusive use, partly positively, with less strings attached, partly negatively, with technical, time, geography, etc, constraints variables. All factors will have to be monitored jointly by incumbent and shared users, based on control systems, under NRA supervision.

Moreover, there are several factors which should be included in the valuation of shared spectrum. For instance, LSA sharer(s) might need to build their own network or to add network hardware and software elements to use shared spectrum.

Overall, the impact of sharing terms and conditions, and uncertainty and risks generated by sharing spectrum, can be synthesised in a mitigation coefficient to be used in the process of valuation and pricing of shared spectrum. Its value can vary between 1 and 0, where 1 corresponds to a situation very close to exclusive use, while the mitigation coefficient is equal to 0 if the constraints are so overwhelming that they annihilate business perspectives.



The mitigation coefficient is at the crux of the translation of the specific LSA technical conditions into business valuation. It will have to take into account a series of factors like availability, QoS, duration, predictability, certainty, flexibility, harmonisation, scale, complexity, and of course specific costs.

Then, the issue is to understand what kind of assignment method would best help determine the ASA/LSA value/price, taking into account the mitigation coefficient.

V. The toolkit of valuation and pricing methodologies

Beyond general considerations of fairness and transparency, little attention has been paid until now on the valuation/pricing aspects of ASA/LSA.

Next generation forms of spectrum access challenge pre-defined forms of assignment, whether they are administrative, market, or collective use.

Some efforts should be devoted to outlining a high level set of considerations on the relevance and adequacy of our current valuation/pricing toolkit to the wide range of sharing possibilities envisaged in European and US regulatory bodies. One cannot but wonder whether the toolkit provides us with what we need for day the middle ground scenarios will have to be implemented. Actually, the valuation/pricing angle also has its own range, with exclusive use, long-term (years) authorizations at one extreme, corresponding to auctions of diverse forms on the one hand, shared use bordering on the opportunistic on the other, with some kind of spot pricing mechanism on the other.

A lot of studies have been devoted to spot pricing of spectrum access, but they do not seem to correspond to realistic technical and business scenarios.

Not all models will be applicable and applied in real life. It seems interesting, however, to outline an all-purpose valuation/pricing scenario that would apply in a comprehensive and consistent manner to all forms of spectrum use in the same application cluster range [37], from exclusive to shared and collective, bringing us closer to a consistent, sustainability objective. This approach seems more feasible with a federal agency in charge of spectrum, that would grant licenses of different geographic extension, different durations, from very short term to multi-year, and that would establish fees accordingly like a land owner or property developer.

In order to make the relevant choices concerning valuation/pricing for shared spectrum, it seems necessary to survey general high-level principles of valuation and pricing methodology. The valuation of spectrum can result either from a mostly top-down process, by which the monetary value attached to spectrum is the result of a computation, or from a pricing process which is a bottom-up process where the monetary value results from a confrontation of supply and demand. As indicated by the ITU Regulation Toolkit [38]: “Spectrum is either valued using prices in market transactions (auctions, spectrum trading or leasing) or by administrative means.” The opposition is not absolute, however, as supply and demand considerations intervene in valuation, and computations by the agents involved take place in supply and demand.

A. *Administrative pricing*

What is usually referred to as administrative pricing is actually a mixed valuation/pricing process.

Administered pricing mechanisms are employed by NRAs to set spectrum prices. Prices can be set in order to recover spectrum management costs (fee recovery) or to actually reflect the market value of spectrum. In this latter case, analytical and modelling techniques are used to develop prices that reflect the underlying spectrum value [38].

1) *Fee recovery*

Spectrum management activities, such as issuing, maintaining data, interference monitoring and enforcing licenses, impose costs on NRAs. Therefore, NRAs usually set up license fees for spectrum use sufficient to recover spectrum management costs. Several methods can be used to determine the level of the fees. They can include detailed costing models to establish which licenses have imposed which costs, or rules of thumb, such as setting charges on the basis of a percentage licensee’s turnover. Indirect or common costs can also be allocated by means of different methods, for instance, based on licensees in proportion to the direct costs imposed or on the amount of spectrum (e.g. in MHz) included in each license. However, the legacy of former price settings and subjective NRA’s judgments may influence the process of setting fees [38].

2) *Administered incentive pricing*

The Administered Incentive Pricing (AIP) method is a process of determining spectrum valuation by a regulator aimed at achieving an efficient use of the spectrum. This scheme is Administered, as prices are set by NRAs, and Incentive, as the price level is intended for users to use spectrum in the most efficient way. AIP simulates market mechanisms, and the prices set can be seen as proxies of market prices. AIP is used in some countries, such as the UK, which has been a forerunner in the field, introducing AIP in 1998. It has been also implemented in Australia and New Zealand, seeking to avoid auctions while maintaining market-oriented fees [38]. There exist different methodologies to simulate a market context and calculate the economic value of spectrum use.

a) Technical approaches

Incentive prices can be determined taking into account several key technical factors such as:

- Amount of spectrum used (bandwidth and geographic area);
- Population covered and location of use (higher values for urban areas)
- Frequency band (coverage and data carrying capacity – higher values in bands that are internationally harmonised and in bands with better propagation characteristics);
- Type of service;
- Level of exclusivity;
- Number of terminals;

The main challenge is to actually set the right price level. In fact, in case of overestimation, spectrum may remain unused and will provide no benefits. On the contrary, in case of underestimation users might not be incentivised to use spectrum more efficiently, which might lead to spectrum shortage [39].

b) Economic approaches

Two economics approaches can be distinguished: the opportunity cost[3] of spectrum use and the net present value (NPV) approach discounting future revenues associated to spectrum use. With regard to the former, a clear example is the AIP mechanism implemented by Ofcom in the UK. Spectrum pricing is based on the marginal value of the spectrum to the user, taking into consideration the amount of congestion in a given band and/or locality, meaning that lower prices correspond to less congested areas. The opportunity cost is defined as the "additional costs of the least-cost practicable alternative" [40]. Therefore, most evaluation models involve a calculation of marginal costs associated with network infrastructure, including equipment and construction costs, as well as cost of capital or labour. Some of these costs can be known or at least well estimated, through benchmarking and survey of existing equipment markets. This is particularly helpful if the spectrum being valued is harmonised across multiple markets, leading to predictable economies of scale and scope in manufacturing [38].

The main criticism raised against the AIP approach based on the opportunity cost of spectrum use, which is also the main justification of the other economic approach, is that users assess the value of spectrum considering not only opportunity costs but also the projection of future revenues associated to several possible spectrum uses. Thus, the best way to determine spectrum values is to use the net present value concept (NPV) to calculate expected net present values of future returns. They are determined based on calculations of all inputs (spectrum, land, equipment, maintenance) using their market prices plus a value attributable to spectrum, related to the flexibility in how the frequencies can be used. Thus, technology flexibility and service neutrality contribute to spectrum values. Benchmarking approaches can be applied to calculate with a certain degree of reliability the potential future revenues associated to spectrum use, looking at data on similar services or identical services in other markets [38]. It is generally believed that opportunity cost approach is easier to be adopted as less information are required compared to the other approach which requires the determination of cash flows. However, AIP mechanisms are in generally perceived as complex and can lead to spectrum value underestimation or overestimation [41].

(1) Opportunity cost approach

This approach is based on the main idea that generally producers set up the production process at the level that ensures the minimization of the costs

[3] The opportunity cost of spectrum is defined as the economic value associated with the best alternative use of spectrum.

of inputs. The same goes for spectrum: users, including the opportunity cost of spectrum use in their decision-making process, would be incentivized to return unused or underutilized spectrum, instead of paying the charge which cannot be economically justified [40]. The opportunity cost of spectrum use can be determined by estimating the other resources that would be saved if the same spectrum were redeployed to produce another service, or the extra costs, which would be incurred if it were not available to provide the service for which it is currently employed, so service has to be provided with less spectrum. Users may be also encouraged to use spectrum in a more efficient and rational manner, for example adopting spectrum-saving technologies, as this translates in lower fees. In such a way productive efficiency can be gained [38]. If spectrum users are not exposed to the opportunity cost of spectrum use, they will generate inefficiencies and the opportunity cost will be carried by the State and ultimately by consumers. A big draw of administered pricing for LSA results from the anticipated prevalence, as least in a first stage, of sharing with public services.

(2) Benchmark approach

Benchmarking approach derives spectrum value by using observed prices paid by in other market transactions (e.g. auction or spectrum trading) users providing similar services, for the same or related frequencies in the same or other countries. Whilst the strength of the benchmarking approach lies in the fact that it is based on actually demonstrated willingness to pay, the main problem is that like for like comparisons can be more or less realistic. It is therefore important to implement benchmarking approaches with caution [42]. In a 2011 Plum report for Vodafone, it can be read that it is difficult to control the impact on prices of several factors such as: 1) the frequency range and the size of the blocks sold; 2) the technologies and services that can use the band; 3) the existing spectrum holdings of bidders; 4) local economic, competitive and demographic circumstances; 5) expectations of and confidence in future revenue growth which varies from time to time. Moreover, the timing of spectrum releases and the availability of information influence the prices, as well [41].

B. AUCTIONS

Spectrum auctions are means of using market-generated prices to assign licenses. In an auction, licenses are awarded on the basis of bidding among competing applicants and go to the bidders offering either the highest monetary sum, or a different sum depending of the auction design. In recent years, Auctions have become well known and established approaches among many NRAs in the world [38].

Spectrum auctions are presented as a more efficient and transparent, fairer and faster mechanism of assigning spectrum licenses, in particular when demand exceeds supply, compared to administrative assignments. They overcome the weaknesses of mechanisms such as comparative hearing or beauty contest, which inevitably involve a subjective judgment of NRAs. The key advantage heralded for auctions procedures is that they assign the licenses to the users, which bid the most, meaning to the ones who assign the spectrum the highest value. This is meant as a reliable way to ensure that spectrum is employed in the most productive use, as the users who are willing to pay the most should be the ones who are willing to manage the asset more efficiently. Moreover, if the auction process is properly designed and conducted, the winning bidders are clearly identified. Where auctions are used to assign spectrum the opportunity cost of the spectrum is paid through the auction process [40].

Auction procedures can be designed in different ways. Moreover there exist different spectrum license fee payments methods. Four main categories can be identified: upfront fees, instalments, usage fee or rents, and royalties, which can also be combined together.

1) Auctions on upfront fees

In auctions on lump-sum fees, licensees are asked to pay the full amount of license fees in one go. In this way NRAs can have immediate or predictable access to the payment [45]. Moreover, NRAs can also ask upfront payment of bids, mainly to reduce default risk between the auction and the sale closing [46]. In case of a bidder withdrawing its participation to the auction, possible penalty fees can be covered with its upfront payment. Moreover, an upfront payment can also be seen as sign of commitment from the bidder [47]. Auctions on upfront fees for commercial uses of spectrum have been popular in many countries on all continents since the late 1990s.

2) Auctions paid in instalments

In certain circumstances NRAs can propose payment by instalments, by which that license fee payments are spread over a predetermined period of time. When governments are not overwhelmed by urgent budget needs, this mechanism makes sense, as the payment schedule is commensurate to the lifecycle of the network, possibly the duration of the license[46]. Moreover, bidders might find it attractive as the upfront capital requirement for the license itsef is reduced, making more capital available for investing in the network. Thus, it can attract more interest from bidders, and auction results can be improved. In fact, more participation in an auction likely translates in higher net present bid amounts. However, this represents the main inefficiency as well, as attractive instalment payment terms may cause speculative biddings. After such an experience, FCC no longer offers instalment payments [47], although Denmark still does.

3) Auctions on yearly usage fees (royalties or rents)

Market mechanisms to determine the valuation and pricing of frequencies can take the form of auctions on yearly usage fees. Yearly fees can be proportional to the revenue generated (royalty), or correspond to the intrinsic characteristics of the licensed frequency band (rent).

Royalties are a form of revenue –and risk- sharing between administrations and spectrum licensees, taking into consideration the user's performance. There are two categories of royalties: ad valorem royalties, determined as a percentage share of actual revenue, or unit royalties calculated by multiplication of the units sold and the royalty per unit. In theory, royalties increase the auction revenue in two ways. First, royalties alleviate part of the risk otherwise borne by the firm and, if the firm is risk-averse, raise the firm's willingness to pay. Second, royalties stimulate the bidding competition, as they reduce the effect of differences in valuations among the bidders. Balancing positive and negative effects, royalties can be beneficial for both governments and licensees [45]. A problem is that user's income, and consequently royalties calculation, are unpredictable, as is the market. Moreover, calculating royalty payments do not single out users profit related to the license use only. Moreover users might adopt accounting methods to underestimate profits and pay less royalties [48]. While the FCC decided against royalties, Hong Kong has adopted an auction model whose payment setting is based on a combination of upfront lump-sum fees and royalties, which intends to be balanced and mutually beneficial for licensor and licensees [45].

Bidding can also take place on spectrum usage fees or rents. Contrary to royalties, rents are not related to the profits of the licensee, but to the characteristics of the frequency band. Auctions on yearly usage fees (rents) can economically converge with upfront fees paid in instalments, when the latter correspond to the duration of the license.

Auction on yearly fees, either royalties or rents, are a feasible form of market mechanism, reflecting the concerns of a risky, capital-intensive industry.

VI. Choosing Valuation and Pricing Methods

The choice of valuation and pricing methods for ASA/LSA calls for high-level principles. The priority is, they have to correspond to the current period requisites: encouraging investment, innovation, and promoting competition. Then, the assignment procedures must be comprehensively and consistently applicable to the largest possible range of spectrum.

A. Spectrum management as property management

A frequent metaphor in spectrum management is that of a property manager. The spectrum "manager", the government administration entity or entities in charge of allocating and assigning the radio spectrum, has to meet the needs of a variety of users and customers, non-commercial and commercial, short term or long term. As a difference to a real estate property management however, it manages the totality of the resource, the spectrum, and not only its own properties, however big. In addition, it knows this property has to be exploited always more efficiently, more "densely" over time, but it cannot be quantitatively expanded. The spectrum manager portfolio is composed of licensed frequencies, frequencies that can be made available at various times for exclusive use, if so decided, and frequencies that their incumbent only partially uses, and that can be considered for sharing.

The spectrum manager knows it is operating in an environment characterized:

- Economically by networks effects, which spontaneously result in oligopolies, and, if left unchecked, result in monopolistic behaviours;
- Technically by fast pace changes, which make difficult forecasting the amount and modalities of spectrum usage beyond the technologies currently being deployed, or soon to be deployed.

Consequently, and in order to make the most of the spectrum resource both for the general public and individual customers, the spectrum manager is careful in considering relinquishing property rights over the spectrum, beyond the life cycle period of investments in current technologies.

Notwithstanding the benefits associated with the adoption of this mechanism, many experts vigorously argue that auctions can lead to critical inefficiency. In particular, it has been noted how often bidders have overpaid for licenses, the auction process becoming a lucrative source of income for national governments [43]. Prime example is the 3G auctions in Europe, which have attracted great attention by generating billions of Euros from bidders [40]. Moreover, problems related to competition may arise as competition may be restricted by users with significant market power, leaving in the shadow smaller and weaker players [44].

Providing the current incumbents, part of an oligopoly, with exclusive long-term property rights is hard to reverse, and present a strong risk of:

- Being stuck with a restricted number of companies with strong specific competencies today, but unpredictable ones over time;
- Preventing the deployment by new entrants with distinct competencies of innovative technologies to be deployed as the next generation beyond the ones currently in use.

Many argue that market mechanisms can handle a situation like this, with the incumbents either being able to surf on the successive waves of technologies, or, alternatively, trading their spectrum properties. However, we have witnessed first-hand in the last decade the potential limitations and vagaries of "market mechanisms", in real estate or financial services for instance, resulting in years of stagnation and loss of millions of jobs in Europe and the US.

In a long-term technology evolution perspective, it is important that assignment of the frequency bands should not provoke long-term, or worse, definitive, spectrum fragmentation. The duration of the licenses, in particular in the shared case, which is an evolutionary scheme, should be proportionate to the life cycle of the network investments entailed. The spectrum property manager should be able to optimize comprehensively and consistently over time the allocation of frequency bands. In order to promote innovative spectrum uses, it gets help from market mechanisms. But it has to prevent the risks of non-competitive, non-innovative, licensee behaviours, in particular spectrum hoarding, that consists in keeping licensed spectrum idle in order to fend off potential competitors, or wait for an increase in its trading value.

It follows, in the case of shared spectrum, which will go through an exploratory period, license duration should stick to the payback period of the investments put in place.

B. A role for administrative pricing?

Administrative pricing was presented earlier in its main varieties: fee recovery, incentive, and benchmarking. In general, the length and complexity of administrative procedures make an awkward match to the working and dynamics of the services and technologies expected to take place within a sharing framework. This assertion has to be nuanced however. In case we are looking at LSA between a public entity incumbent, and commercial operators as LSA licensees, administered incentive pricing might come out as an interesting trade-off, acknowledging both the public feature of the considered frequency band, and the commercial orientation of the shared licensee, thus avoiding culture shock. The incentive level ought to be an informed comparison with the valuation of frequency bands where similar services are provided, adjusted by the mitigation coefficient. We know benchmarking and opportunity costs are burdened with numerous uncertainties: how far are the frequency bands comparable, do we have enough data to establish reliably significant values, etc. LSA being in a pioneering phase, the latter requirement, in particular, is not fulfilled. Eventually, however, we should not rule out AIP, market oriented, but under administration control, that could provide a welcome second-best.

C. Implementing Market mechanisms

Market mechanisms should play a central role in spectrum assignment for commercial uses. The time has come, however, to consider fully their variety, and, in particular, fully assess the auction mechanism that has prevailed in mobile cellular services for now more than a decade.

1) Overall assessment of auctions -as currently conducted- in the case of shared spectrum

Spectrum auctions were designed at a time of financial exuberance, loss of regard for the realities of the productive economy, blind faith in narrowly defined market mechanisms, use of fiscal expedients to cope with always deeper imbalances in public spending. In the process, the mobile telephony industries have shifted into oligopolies. Are those oligopolies competitive: yes and no. On the surface, and under close regulatory scrutiny, they comply with competitive requirements. However, the repeated assignment of frequencies over a decade to the same bunch of 3 or 4 companies in each domestic market is not what we would call the image of a competitive market process. Regulators, despite difficulty of sorting out precisely structure and behaviour competitive factors, have often had to take special steps to allow new entrants, or prevent exits.

MNOs have become willy-nilly a funding channel for needy government budgets. We cannot but think this has created the new version of the capture of the regulator. It was analysed and denounced by the early critics of monopoly regulation in the seventies [49], and led to the awkwardly named “deregulation” movement, first in the airline industry, then in telecommunications.

Presently, in the US, where the mobile oligopoly is tight, and the rates are high, the FCC is considering taking steps for promoting competitors. In Europe, at least in some countries, rates are low, but the investment capabilities of MNOs are seriously hampered by a fragmented industry structure. Low rates and market fragmentation combine with punitive, repeated, levies on operators exerted by governments, even before they have earned a cent, to account for a damaging investment gap in the Community.

The time might have come, not to get back to the dreams of universal unlicensed spectrum of the early millennium, but to a more open and innovative view of the mobile services market. Practical considerations ought to be given to introducing elements of competition, or at least contestability, and to let the door open to innovation, be it in technologies, in services, and in letting in new entrants, small of big.

Strategies to let the mobile services industry bring all the benefits, short-term or long-term it can, should prevail over easy money for the government budgets considerations. Grandstanding but misguided speeches of abstract market principles should not look away from reality. Assignments principles should be defined to benefit consumers, investments, and all industry sectors that can take advantage from a competitive and innovative wireless services industry.

The introduction of ASA/LSA is a good opportunity. It remains inscribed within the existing regulatory framework. But at the same time, it can

pave the way to innovative services, new modalities of service provision, and the regulatory rules that go with it.
The shortcomings of upfront fee auctions are compounded it the case of LSA/ASA by the high risk of impracticality: markets are not well equipped, or reluctant, to deal with shared goods and services (see the attempts to auction bands with public service provision in the US). Consequently, we think, LSA/ASA should not be auctioned in the same way as exclusive rights.

2) Bidding on rents or royalties

It is of interest to design an assignment method that avoids the shortcomings of upfront fee auctions, while preserving the advantages of market mechanisms. It is analogous to the rents on real estate market, in the sense that it actually consists in bidding on usage fees or rents. [50], [51] and [45] have compared different methods of spectrum license fee payments. Kwon's conclusion: "…royalties have a stronger effect on facilitating investment in volatile business environments than do upfront-lump sum fees" [51, p. 133], applies even strongly in the novel case of shared access. Auctions could be conducted on rents (fixed usage fees), royalties (linked to income, profit or turnover), or a mix of the two.

D. Criteria for next generation pricing of spectrum

To summarise, it is fair to say the criteria to which ASA/LSA assignment should correspond are:

1. Feasibility and adaptability
2. Open to technology and service innovation and encourage investment
3. Robust enough to be applicable to changing spectrum access technologies over time
4. Compliance with market mechanisms and competition
5. Consistency: similar activities, for instance commercial, or non-commercial, are submitted to the same valuation/pricing regime.
6. Consistent with previous assignments modes for similar service provision
7. Pro-competitive: should not result in establishing and protecting oligopolies
8. Future proof: Provides a dynamic transition course for future assignment modes

The table below proposes a preliminary assessment of the AIP and auctions approaches with regards to these criteria. We see the outcomes are nuanced, although AIP and auctions on yearly fees emerge as superior.

		AIP	Auctions on lump sums	Auctions on yearly usage fees
1	Feasibility and adaptability	++	++	Adjustable over time +++
2	Open to technology and service innovation and encourage investment	Not very flexible +	Might deter service providers +	Better acceptance +++
3	Robust enough to be applicable to changing spectrum access technologies over time	++	Risk of incumbents sluggishness +	Open to new entrants and new technologies +++
4	Compliance with market mechanisms and competition	Hard to adjust +	Risk of reinforcing oligololy +	Favours open competition +++
5	Consistency with other spectrum assignment methods	++	++	++
6	Consistent with previous assignments modes for similar service provision	+	Conforms to prevalent assignment mode today +++	+
7	It should not result in establishing and protecting oligopolies	++	+	More affordable for new entrants +++
8	Future proof: Provides a dynamic transition course for future assignment modes	+	+	The most flexible +++

VII. CONCLUSIONS

As indicated by ETSI [29]: “The possibility of lower cost, shorter-term, licensing options provided by the LSA regime could foster new innovative ideas and contribute to economic growth throughout the CEPT countries”.

What valuation/pricing scheme is warranted to meet these objectives, and, in Europe in particular, what can help the EU catch up and bridge its telecommunications investment gap?

The issue of valuation/pricing of ASA/LSA, can be addressed by the decision maker as business as usual: auctioning out the considered band as has been the case for mobile telephony bands recently in the form of auctions on down payment upfront fees? This has been obviously disastrous and has contributed to the poor situation of the European telecoms sector.

An innovation-oriented policy, however, would have the decision maker consider the innovative character of ASA/LSA and aim at a valuation pricing mechanism especially conducive to innovation and new entrants [52].

In the new phase ahead, with LSA playing a new role, Europe should get rid of the upfront fees auctions mechanisms.

Given the variety of potential spectrum sharing situations, it will not be possible to adopt just one best valuation and pricing scheme. In case for instance, LSA is seen as a complement to existing licenses to allow carrier aggregation and increase capacity, the interested operators are limitatively listed, and administered incentive pricing can take place. In the same spirit, if a consultation conducted by one administration shows the demand for the considered frequencies do not exceed their supply, it would not make sense to put up an auction.

Is there is just one best solution, or, considering the variety of combinations of shared users, often associating public and commercial entities, should we settle for case-by-case? It seems advisable to make informed choices between the alternative approaches we have selected.

Our proposed action plan would be the following: In a first stage, and if the frequency band considered for LSA is seen as essentially a complement to the existing spectrum portfolio of MNOs, putting in place a temporary licensing mechanism, based on Administered Incentive Pricing, allowing for an experimental period, to be prolonged or not, depending on the success encountered.
Alternatively, or in a second stage, emphasising the innovative outcomes expected to take place in the LSA bands, auctions by payment over time: instalments, auctions on yearly usage fees, with set aside spectrum provisions for new entrants, would create the economic conditions for an efficient use of the radio spectrum.

REFERENCES

[1] J. Khun-Jush, P. Bender, B. Deschamps and M. Gundlach, “Licensed shared access as complementary approach to meet spectrum demands: Benefits for next generation cellular systems”, in ETSI Workshop Reconfig. Radio Syst., Cannes, France, Dec. 2012. [Online]. Available: http://docbox.etsi.org/workshop/2012/201212_RRS/PAPERS/ABSTRACT_KHUNJUSH_Final.doc.pdf.

[2] RSPG (2013, Nov.). Opinion on Licensed Shared Access. [Online].Available: https://circabc.europa.eu/d/d/workspace/SpacesStore/3958ecef-c25e-4e4f-8e3b-469d1db6bc07/RSPG13-538_RSPG-Opinion-on-LSA%20.pdf.

[3] Cisco VNI Forecast (2014, Feb). Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2013-2018, Cisco Public Information. [Online]. Available: Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2013-2018.

[4] A. Nicita, M. A. Rossi (2013, June). Spectrum crunch vs. spectrum sharing: exploring the “Authorised Shared Access” model. Communications & Strategies, No. 90, 2nd Quarter 2013, pp. 17-40. [Online]. Available: http://ssrn.com/abstract=2421169.

[5] A. Durantini, M. Martino (2013, Feb.). The spectrum policy reform paving the way to cognitive radio enabled spectrum sharing. Telecommunications Policy. [Online]. 37 (2-3), pp. 87-95. Available: http://www.sciencedirect.com/science/article/pii/S0308596112001814.

[6] Ingenious Consulting Network (2011, May.). Authorised Shared Access (ASA) An evolutionary spectrum authorisation scheme for sustainable economic growth and consumer benefit. Presented at the 72nd Meeting of the WG FM, Miesbach, Germany. [Online].

[7] J. M. Peha (2009, Apr.). Sharing Spectrum Through Spectrum Policy Reform and Cognitive Radio. Proceedings of the IEEE, 97(4), pp. 708-719. [Online]. Available: http://ieeexplore.ieee.org/xpl/articleDetails.jsp?arnumber=4812027.

[8] Digital Europe (2013, Feb.). Position Paper on Licensed Shared Access (LSA) Common Understanding, Status and Next Steps. [Online]. Available: http://www.digitaleurope.org/DesktopModules/Bring2mind/DMX/Download.aspx?Command=Core_Download&EntryId=519&PortalId=0&TabId=353.

[9] European Parliament and the Council of the European Union (2012, Mar.). Decision No. 243/2012/EU of the European Parliament and of the Council of 14 March 2012 establishing a multiannual radio spectrum policy programme. [Online]. Available: http://www.cept.org/files/9421/EU%20Decision%20on%20RSPP%20(art.8.3).pdf.

[10] RSPG (2011, Feb.). Opinion on Cognitive Technologies, February 2011. [Online]. Available: http://rspg-spectrum.eu/wp-content/uploads/2013/05/rspg_10_348_ct_opinion_final1.pdf.

[11] European Commission (2012, Sept.). Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions Promoting the shared use of radio spectrum resources in the internal market, COM(2012) 478 final. [Online]. Available: http://ec.europa.eu/digital-agenda/sites/digital-agenda/files/com-ssa.pdf.

[12] European Commission (2012, Apr.). Mandate to CEPT to develop harmonised technical conditions for the 2300-2400 MHz (2.3 GHz) frequency band in the EU for the provision of wireless broadband electronic communications services. [Online]. Available: https://mentor.ieee.org/802.18/dcn/14/18-14-0027-00-0000-ec-mandate-2-3-ghz-band.pdf.

[13] FCC (2012, Dec.). In the Matter of Amendment of the Commission's Rules with Regard to Commercial Operations in the 3550-3650 MHz Band, Notice of proposed rulemaking and order. [Online]. Available: https://apps.fcc.gov/edocs_public/attachmatch/FCC-12-148A1.pdf.

[14] J. Scott Marcus, G. Pogorel, F. Pujol (2013, June). The Radio Spectrum: A Shift in Paradigms? Introduction. Communications & Strategies. [Online]. No. 90, 2nd Quarter 2013, pp. 11-16. Available: http://www.idate.org/fr/Digiworld-store/Collection/Communications-Strategies_18/No-90-The-radio-spectrum-A-shift-in-paradigms-_750.html.

[15] E. M. Noam (1998, Dec). Spectrum Auctions: Yesterday's Heresy, Today's Orthodoxy, Tomorrow's Anachronism. Journal of Law and Economics. [Online]. Available: http://www.citi.columbia.edu/elinoam/articles/SPECTRM1.htm

[16] H. Oniki (2009, May). Designing a System for reallocation of Spectrum: Implications for a Conceptual Study. Osaka-Gakuin Review of Economics. [Online]. 23(2), 2009, pp.1-82. Paper also presented at the 36th Research Conference on Communication, Information, and Internet Policy (TPRC 2008), Arlington, VA, USA, September 26-28, 2008, and at Workshop on Spectrum Valuation for 3G Services: Application of the 1900 MHz band in Thailand, November 14, 2008, Bangkok. Available: http://www.ab.auone-net.jp/~ieir/eng/publication/chrono.html#2009.

[17] N. Kroes, "Spectrum sharing – a boost for wireless throughout Europe", Sept. 3, 2012. [Online]. Available: http://ec.europa.eu/commission_2010-2014/kroes/en/blog/spectrum-sharing.

[18] Prepared remark of FCC chairman Tom Wheeler at "Wireless Spectrum and the Future of Technology Innovation" Forum, The Brookings Institution, Washington, DC, March 25, 2014. [Online]. Available: http://benton.org/node/178991.

[19] ETSI, Reconfigurable Radio System, ETSI Technology Leaflets. [Online]. Available: http://www.etsi.org/images/files/ETSITechnologyLeaflets/ReconfigurableRadioSystem.pdf (accessed June 3, 2014).

[20] ITU News (2012). S. Pastukh Chairman ITU-R Working Party 1B, "Software-defined radio and cognitive radio systems", No. 1. [Online]. Available: https://itunews.itu.int/en/2076-Software-defined-radio-and-cognitive-radio-systems.note.aspx (accessed June 3, 2014).

[21] ITU (2009). Report ITU-R SM.2152 Definitions of Software Defined Radio (SDR) and Cognitive Radio System (CRS), Geneva, Switzerland. [Online]. Available: http://www.itu.int/pub/R-REP-SM.2152-2009 (accessed June 3, 2014).

[22] J. Mitola III, G. Q. Maguire Jr (1999, Aug.). Cognitive radio: making software radios more personal. Personal Communications IEEE. [Online]. 6(4), pp. 13-18. Available: http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=788210.

[23] CEPT ECC Newsletter, "Licensed Spectrum Access opens new opportunities", October 2013. [Online]. Available: http://apps.ero.dk/eccnews/october-2013/index.html.

[24] Deloitte (2014, Jan.). The Impact of Licensed Shared Use of Spectrum, a report of the GSM Association prepared in collaboration with Realwireless. [Online]. Available: http://www.gsma.com/spectrum/wp-content/uploads/2014/02/The-Impacts-of-Licensed-Shared-Use-of-Spectrum.-Deloitte.-Feb-20142.pdf.

[25] CEPT ECC (2014, Feb.). ECC Report 205 Licensed Shared Access (LSA). [Online]. Available: http://www.erodocdb.dk/Docs/doc98/official/pdf/ECCREP205.PDF.

[26] RSPG (2011, Nov.). Report on Collective Use of Spectrum (CUS) and other spectrum sharing approaches. [Online]. Available:

http://rspg.ec.europa.eu/_documents/documents/meeting/rspg26/rspg11_392_report_CUS_other_approaches_final.pdf.

[27] Plum Consulting (2013, Dec.). The economic benefits of LSA in 2.3 GHz in Europe. A report for Ericsson, NSN and Qualcomm. [Online]. Available: http://www.plumconsulting.co.uk/pdfs/Plum_Dec2013_Economic_benefits_of_LSA_2.3_GHz_in_Europe.pdf.

[28] CEPT ECC (2014, Feb). Draft ECC Decision (14)BB, Harmonised technical and regulatory conditions for the use of the band 2300-2400 MHz for MFCN. [Online]. Available: http://www.cept.org/files/1051/Tools%20and%20Services/Public%20Consultations/2014/Draft%20ECCDec(14)BB%20on%20MFCN.docx.

[29] ETSI (2013, July). Electromagnetic compatibility and Radio spectrum Matters (ERM); System Reference Document (SRdoc); Mobile broadband services in the 2300 MHz-2400 MHz frequency band under Licensed Shared Access regime, TR 103 113 V.1.1.1. [Online]. Available: http://www.etsi.org/deliver/etsi_tr/103100_103199/103113/01.01.01_60/tr_103113v010101p.pdf.

[30] B. Espinosa, "LSA in the 2.3-2.4 GHz band" (PPT), Trial LSA workshop, Helsinki, Finland, Sept. 3, 2013. [Online]. Available: https://tapahtumat.tekes.fi/uploads/d947b274/Espinosa_Bruno-7257.pdf (accessed June 3, 2014).

[31] CEPT ECC FM PT 52, Example of sharing scenario and cross border coordination, Dec. 18, 2012. [Online]. Available: http://www.cept.org/Documents/fm-52/8459/Web-1_Example-of-sharing-scenario-and-cross-border-coordination.

[32] E. Faussurier, "The potential of Licensed Shared Access for the wireless broadband growth. Regulatory aspects of LSA" (PPT), Rome, Italy, Feb. 14, 2014. [Online]. Available: http://www.fub.it/sites/default/files/attachments/2014/02/Faussurier.pdf (accessed June 6, 2014).

[33] M, Palola, M. Matinmikko, J. Prokkola, M. Mustonen, M. Heikkilä, T. Kippola, S. Yrjölä, V. Hartikainen, L. Tudose, A. Kivinen, J. Paavola, K. Heiska. (2014, Apr.). Live field trial of Licensed Shared Access (LSA) concept using LTE network in 2.3 GHz band. Presented at the 2014 IEEE International Symposium on DYSPAN, McLean, VA, US, Apr. 1-4, pp. 38-47. [Online]. Available: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6817778.

[34] J. Leibovitz, 3.5 GHz: New Ideas in the "Innovation Band", Official FCC blog, Apr. 23, 2014. [Online]. Available at: http://www.fcc.gov/blog/35-ghz-new-ideas-innovation-band (accessed May 28, 2014).

[35] T. Youell (2014, Mar.). Firms offer contrasting visions for 3.5 GHz spectrum sharing, PolicyTracker The spectrum management newsletter. [Online]. Available at: https://www.policytracker.com/headlines/will-spectrum-sharing-in-the-3.5-ghz-band-trigger-a-new-paradigm-in-spectrum-management (accessed May 28, 2014).

[36] O. Holland, L. De Nardis, K. Nolan, A. Medeisis, P. Anker, L. F. Minervini, F. Velez, M. Matinmikko, J. Sydor. (2012, Oct.). "Pluralistic Licensing". Presented at the 2012 IEEE International Symposium on DYSPAN, Bellevue, WA, US, Oct. 16-19, pp. 33-41. [Online]. Available: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6478113.

[37] G. Pogorel (2007, Apr.). Nine regimes of radio spectrum management: a 4-step decision guide. Communications & Strategies, (65), pp. 169–184.

[38] ITU and InfoDev, ICT Regulation Toolkit, 5.5 Spectrum Pricing. [Online]. Available: http://www.ictregulationtoolkit.org/5.5 (accessed June 3, 2014).

[39] M. Lundborg, Spectrum Pricing – Theoretical Approaches and Practical Implementation (PPT), LS Summit 2013, July 3, Lichtenau, Germany. [Online]. Available: http://www.lstelcom.com/fileadmin/content/events/ls_summit_13_presentations/5_Presentation_LS-Summit_Martin_Lundborg.pdf (accessed May 23, 2014).

[40] M. Cave (2002, Mar.). Review of Radio Spectrum Management. An independent review for Department of Trade and Industry and HM Treasury. [Online]. Available: http://www.ofcom.org.uk/static/archive/ra/spectrum-review/2002review/1_whole_job.pdf.

[41] Plum Consulting (2011, Mar.). Methodologies for Valuing Spectrum: Review of the Experts' Report, a Report for Vodafone. [Online] Available: http://www.plumconsulting.co.uk/pdfs/PLUM_March2011_Methodologies_for_Valuing_Spectrum_-_Review_of_the_Experts_Report.pdf (accessed May 24, 2014).

[42] ITU (2012, Apr.). Exploring the Value and Economic Valuation of Spectrum, Geneva, Switzerland. [Online] Available: http://www.itu.int/ITU-D/treg/broadband/ITU-BBReports_SpectrumValue.pdf.

[43] W. H. Melody, W. Lemstra, "Liberalization in Radio Spectrum Management" Chapter 8 in M. Finger, R. W. Künneke, "International handbook of Network Industries. The liberalization of Infrastructure", Cheltenham, UK: Edward Elgar, 2011, pp. 123-143.

[44] ITU, "Economic Aspects of Spectrum Management", Rep. ITU-R SM. 2012-1, Geneva, Switzerland, 2012. [Online]. Available: http://www.itu.int/dms_pub/itu-r/opb/rep/R-REP-SM.2012-1997-PDF-E.pdf (accessed May 23, 2014).

[45] Y. Kwon, J. Lee, Y. Oh (2010, Apr.). Economic and policy implications of spectrum license fee payment methods, Telecommunications Policiy. [Online]. 34(3), pp.175-184. Available: http://www.sciencedirect.com/science/article/pii/S0308596109000998 (accessed May 23, 2014).

[46] R. Keck R. (2009, Sept). Instalment payments in spectrum auctions and telecom privatisations. Butterworths Journal of International Banking and Financial Law. [Online] Available:

http://www.macmillankeck.pro/media/pdf/JIBFL_Sept_Keck.pdf (accessed May 23, 2014).

[47] P. Cramton. (2004). The FCC Spectrum Auctions: An Early Assessment, Journal of Economics & Management Stategy. [Online] 6(3), pp. 431-495. Available: http://onlinelibrary.wiley.com/doi/10.1111/j.1430-9134.1997.00431.x/pdf (accessed May 23, 2014).

[48] J. McMillan. (1994). Selling Spectrum Rights, The Journal of Economic Perspectives. [Online]. 8(3), pp. 145-162. Available: http://www.eecs.harvard.edu/cs286r/courses/spring03/papers/mcmillan94a.pdf (accessed May 23, 2014).

[49] Alfred Kahn, The Economics of Regulation, MIT Press, 1970.

[50] E. M. Noam (1995, Dec.). Taking the Next Step Beyond Spectrum Auctions: Open Spectrum Access. IEEE Communications Magazine. [Online]. pp. 66-73. Available: http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=00476925.

[51] G. Pogorel (2003). Radio Spectrum Policy and Management A Turning Point?, Communications & strategies, 49, 1st quarter, pp. 109.

[52] D. Thomas, "Ericsson warns over lack of next-generation network investment", Financial Times, May 26, 2014.

[53] GSA confirms LTE user devices doubled: 1,371 products launched, LTE TDD grows share Available: http://www.gsacom.com/news/gsa_398.php

Bibliography

[1] J. Khun-Jush, P. Bender, B. Deschamps and M. Gundlach, "Licensed shared access as complementary approach to meet spectrum demands: Benefits for next generation cellular systems", in ETSI Workshop Reconfig. Radio Syst., Cannes, France, Dec. 2012. [Online]. Available: http://docbox.etsi.org/workshop/2012/201212_RRS/PAPERS/ABSTRACT_KHUNJUSH_Final.doc.pdf.

[2] RSPG (2013, Nov.). Opinion on Licensed Shared Access. [Online]. Available: https://circabc.europa.eu/d/d/workspace/SpacesStore/3958ecef-c25e-4e4f-8e3b-469d1db6bc07/RSPG13-538_RSPG-Opinion-on-LSA%20.pdf.

[3] Cisco VNI Forecast (2014, Feb). Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2013-2018, Cisco Public Information. [Online]. Available: Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2013-2018.

[4] A. Nicita, M. A. Rossi (2013, June). Spectrum crunch vs. spectrum sharing: exploring the "Authorised Shared Access" model. Communications & Strategies, No. 90, 2nd Quarter 2013, pp. 17-40. [Online]. Available: http://ssrn.com/abstract=2421169.

[5] A. Durantini, M. Martino (2013, Feb.). The spectrum policy reform paving the way to cognitive radio enabled spectrum sharing. Telecommunications Policy. [Online]. 37 (2-3), pp. 87-95. Available: http://www.sciencedirect.com/science/article/pii/S0308596112001814.

[6] Ingenious Consulting Network (2011, May.). Authorised Shared Access (ASA) An evolutionary spectrum authorisation scheme for sustainable economic growth and consumer benefit. Presented at the 72nd Meeting of the WG FM, Miesbach, Germany. [Online].

[7] J. M. Peha (2009, Apr.). Sharing Spectrum Through Spectrum Policy Reform and Cognitive Radio. Proceedings of the IEEE, 97(4), pp. 708-719. [Online]. Available: http://ieeexplore.ieee.org/xpl/articleDetails.jsp?arnumber=4812027.

[8] Digital Europe (2013, Feb.). Position Paper on Licensed Shared Access (LSA) Common Understanding, Status and Next Steps. [Online]. Available: http://www.digitaleurope.org/DesktopModules/Bring2mind/DMX/Download.aspx?Command=Core_Download&EntryId=519&PortalId=0&TabId=353.

[9] European Parliament and the Council of the European Union (2012, Mar.). Decision No. 243/2012/EU of the European Parliament and of the Council of 14 March 2012 establishing a multiannual radio spectrum policy programme. [Online]. Available: http://www.cept.org/files/9421/EU%20Decision%20on%20RSPP%20(art.8.3).pdf.

[10] RSPG (2011, Feb.). Opinion on Cognitive Technologies, February 2011. [Online]. Available: http://rspg-spectrum.eu/wp-content/uploads/2013/05/rspg_10_348_ct_opinion_final1.pdf.

[11] European Commission (2012, Sept.). Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions Promoting the shared use of radio spectrum resources in the internal market, COM(2012) 478 final. [Online]. Available: http://ec.europa.eu/digital-agenda/sites/digital-agenda/files/com-ssa.pdf.

[12] European Commission (2012, Apr.). Mandate to CEPT to develop harmonised technical conditions for the 2300-2400 MHz (2.3 GHz) frequency band in the EU for the provision of wireless broadband electronic communications services. [Online]. Available: https://mentor.ieee.org/802.18/dcn/14/18-14-0027-00-0000-ec-mandate-2-3-ghz-band.pdf.

[13] FCC (2012, Dec.). In the Matter of Amendment of the Commission's Rules with Regard to Commercial Operations in the 3550-3650 MHz Band, Notice of proposed rulemaking and order. [Online]. Available: https://apps.fcc.gov/edocs_public/attachmatch/FCC-12-148A1.pdf.

[14] J. Scott Marcus, G. Pogorel, F. Pujol (2013, June). The Radio Spectrum: A Shift in Paradigms? Introduction. Communications & Strategies. [Online]. No. 90, 2nd Quarter 2013, pp. 11-16. Available: http://www.idate.org/fr/Digiworld-store/Collection/Communications-Strategies_18/No-90-The-radio-spectrum-A-shift-in-paradigms-_750.html.

[15] E. M. Noam (1998, Dec). Spectrum Auctions: Yesterday's Heresy, Today's Orthodoxy, Tomorrow's Anachronism. Journal of Law and Economics. [Online]. Available: http://www.citi.columbia.edu/elinoam/articles/SPECTRM1.htm

[16] H. Oniki (2009, May). Designing a System for reallocation of Spectrum: Implications for a Conceptual Study. Osaka-Gakuin Review of Economics. [Online]. 23(2), 2009, pp.1-82. Paper also presented at the 36th Research Conference on Communication, Information, and Internet Policy (TPRC 2008), Arlington, VA, USA, September 26-28, 2008, and at Workshop on Spectrum Valuation for 3G Services: Application of the 1900 MHz band in Thailand, November 14, 2008, Bangkok. Available: http://www.ab.auone-net.jp/~ieir/eng/publication/chrono.html#2009.

[17] N. Kroes, "Spectrum sharing – a boost for wireless throughout Europe", Sept. 3, 2012. [Online]. Available: http://ec.europa.eu/commission_2010-2014/kroes/en/blog/spectrum-sharing.

[18] Prepared remark of FCC chairman Tom Wheeler at "Wireless Spectrum and the Future of Technology Innovation" Forum, The Brookings Institution, Washington, DC, March 25, 2014. [Online]. Available: http://benton.org/node/178991.

[19] ETSI, Reconfigurable Radio System, ETSI Technology Leaflets. [Online]. Available: http://www.etsi.org/images/files/ETSITechnologyLeaflets/ReconfigurableRadioSystem.pdf (accessed June 3, 2014).

[20] ITU News (2012). S. Pastukh Chairman ITU-R Working Party 1B, "Software-defined radio and cognitive radio systems", No. 1. [Online]. Available: https://itunews.itu.int/en/2076-Software-defined-radio-and-cognitive-radio-systems.note.aspx (accessed June 3, 2014).

[21] ITU (2009). Report ITU-R SM.2152 Definitions of Software Defined Radio (SDR) and Cognitive Radio System (CRS), Geneva, Switzerland. [Online]. Available: http://www.itu.int/pub/R-REP-SM.2152-2009 (accessed June 3, 2014).

[22] J. Mitola III, G. Q. Maguire Jr (1999, Aug.). Cognitive radio: making software radios more personal. Personal Communications IEEE. [Online]. 6(4), pp. 13-18. Available: http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=788210.

[23] CEPT ECC Newsletter, "Licensed Spectrum Access opens new opportunities", October 2013. [Online]. Available: http://apps.ero.dk/eccnews/october-2013/index.html.

[24] Deloitte (2014, Jan.). The Impact of Licensed Shared Use of Spectrum, a report of the GSM Association prepared in collaboration with Realwireless. [Online]. Available: http://www.gsma.com/spectrum/wp-content/uploads/2014/02/The-Impacts-of-Licensed-Shared-Use-of-Spectrum.-Deloitte.-Feb-20142.pdf.

[25] CEPT ECC (2014, Feb.). ECC Report 205 Licensed Shared Access (LSA). [Online]. Available: http://www.erodocdb.dk/Docs/doc98/official/pdf/ECCREP205.PDF.

[26] RSPG (2011, Nov.). Report on Collective Use of Spectrum (CUS) and other spectrum sharing approaches. [Online]. Available: http://rspg.ec.europa.eu/_documents/documents/meeting/rspg26/rspg11_392_report_CUS_other_approaches_final.pdf.

[27] Plum Consulting (2013, Dec.). The economic benefits of LSA in 2.3 GHz in Europe. A report for Ericsson, NSN and Qualcomm. [Online]. Available: http://www.plumconsulting.co.uk/pdfs/Plum_Dec2013_Economic_benefits_of_LSA_2.3_GHz_in_Europe.pdf.

[28] CEPT ECC (2014, Feb). Draft ECC Decision (14)BB, Harmonised technical and regulatory conditions for the use of the band 2300-2400 MHz for MFCN. [Online]. Available: http://www.cept.org/files/1051/Tools%20and%20Services/Public%20Consultations/2014/Draft%20ECCDec(14)BB%20on%20MFCN.docx.

[29] ETSI (2013, July). Electromagnetic compatibility and Radio spectrum Matters (ERM); System Reference Document (SRdoc); Mobile broadband services in the 2300 MHz-2400 MHz frequency band under Licensed Shared Access regime, TR 103 113 V.1.1.1. [Online]. Available: http://www.etsi.org/deliver/etsi_tr/103100_103199/103113/01.01.01_60/tr_103113v010101p.pdf.

[30] B. Espinosa, "LSA in the 2.3-2.4 GHz band" (PPT), Trial LSA workshop, Helsinki, Finland, Sept. 3, 2013. [Online]. Available: https://tapahtumat.tekes.fi/uploads/d947b274/Espinosa_Bruno-7257.pdf (accessed June 3, 2014).

[31] CEPT ECC FM PT 52, Example of sharing scenario and cross border coordination, Dec. 18, 2012. [Online]. Available: http://www.cept.org/Documents/fm-52/8459/Web-1_Example-of-sharing-scenario-and-cross-border-coordination.

[32] E. Faussurier, "The potential of Licensed Shared Access for the wireless broadband growth. Regulatory aspects of LSA" (PPT), Rome, Italy, Feb. 14, 2014. [Online]. Available: http://www.fub.it/sites/default/files/attachments/2014/02/Faussurier.pdf (accessed June 6, 2014).

[33] M, Palola, M. Matinmikko, J. Prokkola, M. Mustonen, M. Heikkilä, T. Kippola, S. Yrjölä, V. Hartikainen, L. Tudose, A. Kivinen, J. Paavola, K. Heiska. (2014, Apr.). Live field trial of Licensed Shared Access (LSA) concept using LTE network in 2.3 GHz band. Presented at the 2014 IEEE International Symposium on DYSPAN, McLean, VA, US, Apr. 1-4, pp. 38-47. [Online]. Available: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6817778.

[34] J. Leibovitz, 3.5 GHz: New Ideas in the "Innovation Band", Official FCC blog, Apr. 23, 2014. [Online].

Available at: http://www.fcc.gov/blog/35-ghz-new-ideas-innovation-band (accessed May 28, 2014).

[35] T. Youell (2014, Mar.). Firms offer contrasting visions for 3.5 GHz spectrum sharing, PolicyTracker The spectrum management newsletter. [Online]. Available at: https://www.policytracker.com/headlines/will-spectrum-sharing-in-the-3.5-ghz-band-trigger-a-new-paradigm-in-spectrum-management (accessed May 28, 2014).

[36] O. Holland, L. De Nardis, K. Nolan, A. Medeisis, P. Anker, L. F. Minervini, F. Velez, M. Matinmikko, J. Sydor. (2012, Oct.). "Pluralistic Licensing". Presented at the 2012 IEEE International Symposium on DYSPAN, Bellevue, WA, US, Oct. 16-19, pp. 33-41. [Online]. Available: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6478113.

[37] G. Pogorel (2007, Apr.). Nine regimes of radio spectrum management: a 4-step decision guide. Communications & Strategies, (65), pp. 169–184.

[38] ITU and InfoDev, ICT Regulation Toolkit, 5.5 Spectrum Pricing. [Online]. Available: http://www.ictregulationtoolkit.org/5.5 (accessed June 3, 2014).

[39] M. Lundborg, Spectrum Pricing – Theoretical Approaches and Practical Implementation (PPT), LS Summit 2013, July 3, Lichtenau, Germany. [Online]. Available: http://www.lstelcom.com/fileadmin/content/events/ls_summit_13_presentations/5_Presentation_LS-Summit_Martin_Lundborg.pdf (accessed May 23, 2014).

[40] M. Cave (2002, Mar.). Review of Radio Spectrum Management. An independent review for Department of Trade and Industry and HM Treasury. [Online]. Available: http://www.ofcom.org.uk/static/archive/ra/spectrum-review/2002review/1_whole_job.pdf.

[41] Plum Consulting (2011, Mar.). Methodologies for Valuing Spectrum: Review of the Experts' Report, a Report for Vodafone. [Online] Available: http://www.plumconsulting.co.uk/pdfs/PLUM_March2011_Methodologies_for_Valuing_Spectrum_-_Review_of_the_Experts_Report.pdf (accessed May 24, 2014).

[42] ITU (2012, Apr.). Exploring the Value and Economic Valuation of Spectrum, Geneva, Switzerland. [Online] Available: http://www.itu.int/ITU-D/treg/broadband/ITU-BBReports_SpectrumValue.pdf.

[43] W. H. Melody, W. Lemstra, "Liberalization in Radio Spectrum Management" Chapter 8 in M. Finger, R. W. Künneke, "International handbook of Network Industries. The liberalization of Infrastructure", Cheltenham, UK: Edward Elgar, 2011, pp. 123-143.

[44] ITU, "Economic Aspects of Spectrum Management", Rep. ITU-R SM. 2012-1, Geneva, Switzerland, 2012. [Online]. Available: http://www.itu.int/dms_pub/itu-r/opb/rep/R-REP-SM.2012-1997-PDF-E.pdf (accessed May 23, 2014).

[45] Y. Kwon, J. Lee, Y. Oh (2010, Apr.). Economic and policy implications of spectrum license fee payment methods, Telecommunications Policiy. [Online]. 34(3), pp.175-184. Available: http://www.sciencedirect.com/science/article/pii/S0308596109000998 (accessed May 23, 2014).

[46] R. Keck R. (2009, Sept). Instalment payments in spectrum auctions and telecom privatisations. Butterworths Journal of International Banking and Financial Law. [Online] Available: http://www.macmillankeck.pro/media/pdf/JIBFL_Sept_Keck.pdf (accessed May 23, 2014).

[47] P. Cramton. (2004). The FCC Spectrum Auctions: An Early Assessment, Journal of Economics & Management Stategy. [Online] 6(3), pp. 431-495. Available: http://onlinelibrary.wiley.com/doi/10.1111/j.1430-9134.1997.00431.x/pdf (accessed May 23, 2014).

[48] J. McMillan. (1994). Selling Spectrum Rights, The Journal of Economic Perspectives. [Online]. 8(3), pp. 145-162. Available: http://www.eecs.harvard.edu/cs286r/courses/spring03/papers/mcmillan94a.pdf (accessed May 23, 2014).

[49] Alfred Kahn, The Economics of Regulation, MIT Press, 1970.

[50] E. M. Noam (1995, Dec.). Taking the Next Step Beyond Spectrum Auctions: Open Spectrum Access. IEEE Communications Magazine. [Online]. pp. 66-73. Available: http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=00476925.

[51] G. Pogorel (2003). Radio Spectrum Policy and Management A Turning Point?, Communications & strategies, 49, 1st quarter, pp. 109.

[52] D. Thomas, "Ericsson warns over lack of next-generation network investment", Financial Times, May 26, 2014.

[53] M. Chaduc and G. Pogorel. "The Radio Spectrum: Managing a strategic resource". London, UK: ISTE-WILEY, 2008.

[54] A. Nicita, P. L. Parcu (2013). Spectrum Sharing : the case for Authorised Shared Access. Network Industries Quarterly. [Online]. 15(3), pp. 1-7. Available : http://mir.epfl.ch/files/content/sites/mir/files/Newsletter/Vol%2015,%20No%203,%202013/Spectrum%20sharing,%20the%20case%20of%20authorised%20shared%20access.pdf.

[55] P. L. Parcu, A. Nicita, G. Corda, M. A. Rossi, L. F. Bravo (2011, May). Authorised Shared Access (ASA). An innovative model of Pro-competitive Spectrum Management. [Online]. Available: http://ssrn.com/abstract=2174518.

[56] ITU-R (2011, Nov.). Cognitive radio systems specific for International Mobile Telecommunications systems, Report ITU-R M.2242. [Online]. Available: http://www.itu.int/dms_pub/itu-r/opb/rep/R-REP-M.2242-2011-PDF-E.pdf.

[57] CEPT ECC (2014, Feb). Draft ECC Recommendation (14)04, Corss-border coordination for MFCN and between MFCN and other systems in the frequency band 2300-2400 MHz.

[58] M. Matinmikko, M. Mustonen, D. Roberson, J. Paavola, M. Höyhtyä, S. Yrjölä, J. Röning (2014, Apr.). Overview

and comparison of recent spectrum sharing approaches in regulation and research. Presented at the 2014 IEEE International Symposium on DYSPAN, McLean, VA, US, Apr. 1–4, pp. 92-102. [Online]. Available: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6817783.

[59] ETSI (2014, May). Draft TS 103 154 V0.0.12, Reconfigurable Radio Systems (RRS); System Regioements for operation of Mobile Broadband. Systems in the 2300 MHz – 2400 MHz band under Licensed Shared Access (LSA).

[60] ETSI (2014, Jan.). TS 103 235 V0.0.1, Reconfigurable Radio Systems (RRS); System Architecture and High Level Procedures for operation of Licensed Shared Access (LSA) in the 2300 MHz – 2400 MHz band.

[61] CEPT ECC (2012). FM(12)084 Annex 47, Report on ASA concept. [Online]. Available: http://www.cept.org/Documents/fm-52/7844/FM52(12)INFO4_WG-FM-Report-on-ASA-concept.

[62] CEPT ECC (2012, Mar.). ECC Report 172, Broadband Wireless Systems Usage in 2300-2400 MHz. [Online]. Available: http://www.erodocdb.dk/docs/doc98/official/pdf/ECCRep172.pdf.

[63] CEPT ECC (2009, June). ECC Report 132, Light Licensing, Licence-exempt and commons. [Online]. Available: http://www.erodocdb.dk/Docs/doc98/official/pdf/ECCRep132.pdf.

[64] CEPT ECC, Terms of Reference, PT FM52 on 2300-2400 MHz band. [Online]. Available: http://www.cept.org/ecc/groups/ecc/wg-fm/fm-52/page/terms-of-reference.

[65] CEPT ECC, Terms of Reference, FM Project Team 53 on Reconfigurable Radio Systems (RRS) and Licensed Shared Access (LSA). [Online]. Available: http://www.cept.org/Documents/fm-53/8565/FM53(13)02_Terms-of-reference-of-FM53.

[66] RSPG (2008, Nov.). Opinion on Aspects of a European Approach to Collective Use of Spectrum, RSPG08-244 Final, Brussels. [Online]. Available: http://rspg-spectrum.eu/rspg-opinions-main-deliverables/.

[67] RSPG (2013, June). Opinion on Strategic Challenges facing Europe in addressing the Growing Spectrum Demand for Wireless Broadband, RSPG13-521 rev1, Brussels. [Online]. Available: http://rspg-spectrum.eu/rspg-opinions-main-deliverables/.

[68] Qualcomm and Nokia (2011, Jan.). RSPG Consultation on Cognitive Technologies, Qualcomm and Nokia Corporation Joint Response. [Online]. Available: http://rspg-spectrum.eu/consultations/consultation_cognitiv_2010/qualcomm_nokia_0114.pdf.

[69] Ericsson (2013, Oct.). Spectrum Sharing Fast-track capacity with licensed shared access. [Online]. Available: http://www.ericsson.com/res/docs/whitepapers/wp-spectrum-sharing.pdf.

[70] HUAWEI (2013, Jul.). UK Radio Spectrum Report. [Online]. Available: http://www.huawei.com/ilink/uk/download/HW_274552.

[71] Chair MIR of EPFL and FSR (2013). Regulation and performance of electronic communications networks for European citizens, the Network Industries Quarterly. [Online]. 15(3), pp. 1-24. Available: http://fsr.eui.eu/Documents/Journal/Transport/NIQ-Vol15-No3-2013.pdf.

[72] Nokia Siemens Networks (2012, Apr.). Optimised Spectrum Use by Authorised Shared Access. [Online]. Available: http://nl.nsn.com/system/files/document/authorised_shared_access_apr_2012_0.pdf.

[73] NSN (2014, Mar.). Optimising Spectrum Utilisation towards 2020, White Paper. [Online]. Available: http://nsn.com/file/30301/optimising-spectrum-utilisation-towards-2020?download.

[74] NSN (2013, Sept). NSN demonstrates world's first Authorized Shared Access field trial with TD-LTE spectrum, Press Release. [Online]. Available: http://uk.prweb.com/releases/2013/9/prweb11165446.htm.

[75] RAS (2012, Oct.). A white paper on spectrum sharing. [Online]. Available: http://www.ict-qosmos.eu/fileadmin/documents/Dissemination/White_Papers/RAS_Cluster_white_paper.pdf.

[76] Rysavy Research (2012, Jul.). Spectrum Sharing The Promise and The Reality. [Online]. Available: http://www.rysavy.com/Articles/2012_07_Spectrum_Sharing.pdf.

[77] SCF Associates LTD (2012, Feb.). Perspectives on the value of shared spectrum access, Final Report for the European Commission. [Online]. Available: http://ec.europa.eu/digital-agenda/sites/digital-agenda/files/scf_study_shared_spectrum_access_20120210.pdf.

[78] 4G Americas (2013, Oct.). Meeting the 1000x Challenge: The need for Spectrum, Technology and Policy Innovation. [Online]. Available: http://www.4gamericas.org/documents/2013_4G%20Americas%20Meeting%20the%201000x%20Challenge%2010%204%2013_FINAL.pdf.

[79] ETNO (2013, Aug.). ETNO Reply to the Draft Opnion on Licensed Shared Access, Position paper. [Online]. Available: https://www.etno.eu/datas/positions-papers/2013/RD394%20-%20ETNO%20Response%20to%20RSPG%20LSA_Consultation.pdf.

[80] GSMA (2013, Feb.). Licensed Shared Access (LSA) and Authorised Shared Access (ASA), GSMA Public Policy Position. [Online]. Available: http://www.gsma.com/spectrum/wp-content/uploads/2013/04/GSMA-Policy-Position-on-LSA-ASA.pdf.

[81] GSMA (2011, Nov.). GSMA Public Policy Position on spectrum and infrastructure sharing. [Online]. Available: http://www.gsma.com/spectrum/wp-

content/uploads/2012/03/publicpolicypositionspectruminfrastructuresharing.pdf.

[82] K. Werbahc, A. Mehta (2014). The Spectrum Opportunity: Sharing as the Solution to the Wireless Crunch, International Journal of Communication. [Online]. 8, pp. 128-149. Available: http://ijoc.org/index.php/ijoc/article/view/2239/1054.

[83] A. Medeisis, O. Holland, "Policy Suggestions for the Way Forward for CR", Chapter 7, in A. Medeisis, O. Holland (eds.), CR Policy and Regulation: Techno-Economic Studies to Facilitate Dynamic Spectrum Access, Signals and Communication Technology, Springer International Publishing Switzerland, 2014, pp. 349-381.

[84] P. Marques, J. Rodriguez, S. Delaere, P. Delahaye, B. Lecroart, M. Gundlach, D. Triantafyllopoulou, K. Moessner, D. Noguet, "Spectrum Sharing in the EU and the Path Towards Standardization", in Proc. FutureNetworkSummit, July 3-5, 2013, Lisboa, Portugal, pp. 1-9. [Online]. Available: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6633556.

[85] C. Carciofi, D. Guiducci, M. Barbiroli, R. Castrucci, "Analysis of different authorization approaches for the shared access to radio spectrum". Presented at: 24th European Regional Conference of the ITS, Florence, Italy, 20-23 October 2013. [Online]. Available: http://www.econstor.eu/bitstream/10419/88458/1/773100741.pdf.

[86] A. Bunel, D. Lescop, "A new institutional perspective on shared spectrum access issues". Presented at: 24th European Regional Conference of the ITS, Florence, Italy, 20-23 October 2013. [Online]. Available: https://www.econstor.eu/dspace/bitstream/10419/88480/1/773358005.pdf.

[87] A. Bunel, D. Lescop, "Shared Access, cognitive radio and transition issues". Presented at: 19th ITS Biennial Conference 2012, November 21, 2012, Bangkok, Thailand. [Online]. Available: http://econstor.eu/bitstream/10419/72532/1/741720531.pdf.

[88] Telecom Italia, "Licensed/Authorized Shared Access (LSA/ASA)", Reti Mobili e Valorizzazione Frequenze, March 31, 2014, Rome, Italy (PPT).

[89] P. Ahokangas, M. Matinmikko, S. Yrjölä, M. Mustonen, H. Posti, E. Luttinen, A. Kivimäki, "Business models for mobile network operators in Licensed Shared Access (LSA)" (PPT), IEEE DySPAN 2014, April 1-4, 2014.

[90] S. Ciriani, M. Lebourges (2014, Apr.). A new European competition policy for growth driven by profitable investments, The European Commission's policy in light of the modern economic growth theories, Report. [Online]. Available: http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2441662.

[91] E. M. Noam, "The Economists' Contribution to Radio Spectrum Access: The Past, the Present, and the Future", in the Proc. of IEEE, Vol. 100, 2012, pp. 1692-1697. [Online]. Available: http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=06179295.

[92] I. De Michelis di Slonghello, "The Mobile Broadband Perspective. developing Next-generation Networks" (PPT), Florence, Italy, June 1, 2012.

[93] G. Pogorel, "Future Wireless Technologies and Services: Current Challenges for Regulators" (PPT), Session 2 at Workshop Radio Spectrum Management Reform in the Mauritian Context, La Cannelle, Domaines les Pailles, Mauritius, Sept. 6-7, 2012.

[94] M. Gundlach, "Licensed Shared Access (LSA) as complementary approach to meet spectrum demands: Standardization opportunities for RAS cluster projects" (PPT), Future Networks 11th FP7 Concertation Cluster Meeting, Brussels, Feb. 27, 2013.

[95] Qualcomm, "1000x: More spectrum – especially for small cells. Including ASA – a new license model to access underutilized, high quality spectrum" (PPT), Nov. 2013.

[96] Qualcomm, "LSA in ETSI: Standards development and Technical Requirements" (PPT), Feb. 2014.

[97] M. Matinmikko, "Finnish Licensed Shared Access (LSA) trials" (PPT), COST TERRA meeting, Vilnius, Lithuania, Apr. 29, 2014.