Spectrum Crunch vs. Spectrum Sharing:
Exploring the 'Authorised Shared Access' Model (*)

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Abstract: This paper provides an overview of a recently proposed spectrum sharing model – 'Authorized Shared Access' or 'Licensed Shared Access' (ASA/LSA) – and compares it to other sharing models in order to outline its distinctive features and fields of application. The main feature of this new concept is to allow sharing among a limited number of licensees with guaranteed, but shared, spectrum usage rights so as to achieve a comparable quality of transmission as in the case of exclusive individual usage rights to all sharing parties. For this reason, the ASA model is able to support both large-scale and small-scale investments in spectrum-hungry technologies. We conclude that LSA/ASA is a promising new model that, absent 'one-size-fits-all' spectrum management solutions, may provide a valuable tool, complementary to other existing and developing tools, to face the spectrum crunch challenge and to meet the Digital Agenda purposes.

Key words: Spectrum Management, Authorized Shared Access, Spectrum Trading and Leasing, Collective Use, Hybrid Collective Use.

Spectrum policy has never faced as many challenges as it faces today. The set of technological and business developments that goes under the label of 'mobile internet revolution' requires large amounts of "good quality" spectrum available at reasonable terms to fully materialize. On one side, consumers increasingly demand

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spectrum-hungry services and applications with a guaranteed Quality of Service (QoS). On the other, businesses seek to lower the costs of mobile broadband service provision, to obtain higher returns and to engage in activities on a global scale, and thus to exploit economies of scale within and between affected relevant markets.

As recently pointed out by the European Commissioner for the Digital Agenda, Vice-President Neelie Kroes:

> "Users want to be in control, with access to content anytime, anywhere and on any device. This opens the gate to a new ocean of innovation, an ecosystem on top of which new services and business models can soar." [1]

It is now well recognized that this 'new' demand for spectrum capacity faces the risk of a "spectrum crunch". However, it appears somewhat paradoxical that a 'spectrum crunch' shall occur in a world where current usage and utilization patterns of assigned spectrum show systematic underutilization, so that spectrum cannot be said to be intrinsically scarce. This apparent paradox stems from the current institutional design of spectrum policies, which is unable to ensure that spectrum supply adequately meets demand, and therefore constitutes a challenge for policy makers. In our view, the challenge we face today resides in the need to improve access to already available but underutilized spectrum by designing spectrum policies and rules that allow for new forms of sharing of underutilized spectrum. Indeed, most spectrum is presently allocated to valuable uses and assigned to public entities or commercial operators whose rights of use have not been granted through an award procedure (first come, first served; beauty contest, auction, etc.) for commercial use. Both of these actors may be unable or lack the incentives to clear frequency bands even when they do not utilize available spectrum to the fullest possible extent. Non-commercial spectrum users are sometimes prevented from making spectrum available to third parties by national regulations or they may lack appropriate incentives to do so. Commercial spectrum users, on the other hand, may find obstacles in increasing the extent of spectrum utilization in the fact that the institutional framework does not allow them to undertake on an appropriate scale and scope spectrum-related transactions or it does not foresee adequate rules to keep transaction costs at reasonable levels. There is therefore a lack of 'modularity' in spectrum usage and an

[1] Neelie Kroes,"Giving Europe a Mobile Broadband Boost", 2012 Mobile World Congress, Barcelona, 27 February 2012.

absence of a regulatory framework that allows for and/or promotes new forms of sharing, coupling legal certainty with economic and technological flexibility. In addition, it is important to stress that the risk of a 'spectrum crunch' event depends not only on restrictions on the quantity but also on the quality of the available spectrum. This is because, to adequately meet the growing spectrum demand, there is a need for portions of spectrum sufficiently wide to be able to support high data rate services and available on predictable terms so as to enable provision of services with a predictable QoS.

The need for more effective and novel forms of spectrum sharing has been already acknowledged in the relevant international forums. Indeed, recent developments in spectrum policy increasingly identify spectrum sharing as one of the major tools to respond to the spectrum demands of both public and private users. In Europe, for instance, the Radio Spectrum Policy Group (RSPG) has issued a 2011 Report advocating advances towards new forms of collective and shared use of spectrum [2]. The European Parliament and Member States have affirmed in the EU Radio Spectrum Policy Programme (RSPP) that "Member States, in cooperation with the Commission, shall, where appropriate, foster the collective use of spectrum as well as shared use of spectrum" [3]. Finally, the European Commission has ordered a study on spectrum sharing [4] and has issued a Communication on promoting the shared use of radio spectrum resources in the internal market [5]. This awareness has been aptly summarized by Neelie Kroes, who has held that:

> "We must look at novel ways to share spectrum: so that for example, public and commercial users, or different commercial sectors, can benefit from shared access to the same spectrum bands."

In the United States, the debate on spectrum sharing has mostly focused on sharing of federal government spectrum resources. The idea of spectrum

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[2] Radio Spectrum Policy Group, "Report on Collective Use of Spectrum (CUS) and Other Spectrum Sharing Approaches", RSPG11-392 Final, November 2011.

[3] Recital 19, Decision No. 243/2012/EU of the European Parliament and of the Council of 14 March 2012 establishing a multiannual radio spectrum policy programme, *OJ* L 81, 21 March 2012, pp. 7-17.

[4] SCF Associates, "Perspectives on the Value of Shared Spectrum Access: Final Report for the European Commission", Report prepared for DG Information Society and Media, Electronic Communications Policy, Radio Spectrum Policy (Unit B4), 2012.

[5] European Commission, "Communication 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.

sharing, introduced already in 2006, when the National Telecommunications and Information Administration (NTIA), in coordination with the Federal Communications Commission (FCC), first established a Test-Bed to examine the feasibility of increased sharing between federal and non-federal users, has gained further traction after the issue of a 2012 report of the President's Council of Advisors on Science and Technology (PCAST), focusing on ways to improve utilization of Government-held spectrum. A number of initiatives has since been undertaken to expand commercial spectrum sharing opportunities with government.

These policy developments are supported by recent technological evolutions that have opened up additional options for sharing and by theoretical developments on the institutional design of spectrum management. Indeed, new technologies are now available that improve the conditions of cohexistence of multiple users within the same spectrum bands through power and interference reduction techniques, thus enabling greater extents of spectrum sharing (PEHA, 2009). The technological management techniques that allow for spectrum sharing are underlay and overlay technologies, while the main enabling technologies are ultra wideband (UWB) devices, mesh networks, software defined radio (SDR), smart antennae and cognitive radios. Underlay technologies allow for cohexistence of a secondary user whose radio station has a very low spectral power density with a primary user that therefore experiences a limited increase in the noise floor. Active overlay technologies (Dynamic Spectrum Access) allow for more sophisticated cohexistence of primary and secondary users. By allowing for monitoring and dynamic control of spectrum use, such technologies enable secondary users to have access to specified portions of spectrum for a defined time period or within a defined geographical area under controlled conditions.

On the theoretical side, new mechanisms to make spectrum markets work have attracted a great deal of attention. In particular, the debate has focused on market design (CROCIONI, 2009), recourse to options-like tools (BYKOWSKY, 2003), real-time secondary markets for spectrum (PEHA & PANICHPAPIBOON, 2004) and other tools of this sort. However, none of the mentioned theoretical models has gathered sufficient attention to translate into a concrete policy proposal.

There is one recently proposed spectrum sharing solution that, by contrast, has relatively rapidly entered in the policy debate but has not so far attracted much theoretical attention. This spectrum sharing model is the 'Authorized Shared Access' (ASA) model, which was originally proposed by an industry consortium composed by Qualcomm and Nokia (Ingenious, 2010; PARCU *et al*., 2012). The ASA concept corresponds to the notion of Licensed Shared Access (LSA) introduced by the Radio Spectrum Policy Group in its November 2011 "Report on CUS and other spectrum sharing approaches" [6]. The notion of ASA/LSA refers to a form of 'licensed' sharing of underutilised spectrum, released through a process of individual authorisation to a limited number of users. The main feature of this new concept is to allow sharing among a limited number of licensees "with guaranteed, but shared, spectrum usage rights" so as to achieve "a comparable quality of transmission as in the case of exclusive individual usage rights". Thus, the proposed ASA/LSA approach aims at increasing modularity and efficiency of spectrum usage while ensuring predictability of the conditions of spectrum usage and therefore the quality of shared spectrum.

This paper aims at highlighting the novelty of the ASA/LSA model and comparing it to other sharing models in order to outline its distinctive features and fields of application. We conclude that LSA/ASA is a promising new model that goes beyond the traditional distinction between market-based and command-and-control solutions and constitutes a valuable option to face the spectrum crunch challenge and to meet the Digital Agenda purposes. In this regard it is, however, important to stress that ASA/LSA should not be considered as an alternative to existing and emerging spectrum management models, but rather as a complementary tool to increase spectrum utilization. The recent evolution of the theoretical and policy debate has indeed made clear that, given the heterogeneity of devices, applications and technologies whose use requires access to spectrum as well as the heterogeneity in spectrum physical properties (e.g., propagation, throughout, etc.), it is unlikely that a single solution will be able to match all of the needs of an evolving technological and market environment. Thus, multiple complementary tools are needed to address the range of issues raised by the coexistence of different spectrum uses – for instance, commercial and non-commercial – different technologies and diverging and path-dependent national policies. In line with this view, neither ASA/LSA, nor other recently proposed models should be considered 'one-size-fits-all' solutions.

[6] The use of the world 'authorized' in the definition of 'Authorized Shared Access' is meant to emphasize the full compatibility of this model with the existing European electronic communications regulatory framework, and particularly with the 'Authorization Directive'.

ASA/LSA as a new spectrum sharing solution

Authorized Shared Access (ASA) is a new technological, legal, economic and regulatory framework that allows for the dynamic and shared use of spectrum. It enables sharing by relying on database technologies, subject to an authorization scheme of spectrum usage rights. More precisely, ASA is defined as "a regulatory framework that allows for licensed sharing of underutilized spectrum by a limited number of rights holders, in incumbent bands, through an individual authorization scheme following the terms set forth by Directive 2002/20/EC (Authorization Directive)" (PARCU *et al.*, 2012).

The main idea behind the ASA framework is to provide Administrations administrations and incumbent commercial and non-commercial users of spectrum with an additional tool, swiftly available, to exploit the potential economic value of the unused portion of it, thus avoiding underutilization. As mentioned above, both non-commercial and commercial users may not fully utilize the entire spectrum they are entitled to use, so that there is some scope for sharing without jeopardizing existing uses. The holder of public use spectrum, i.e. a public entity (e.g., the military) that provides security, defence, public safety or other services, normally uses spectrum only on a piecemeal basis (partial and/or discontinuous use). The same may apply to a commercial spectrum user who may temporarily or permanently have spare portions of spectrum. These users may be willing to share their spectrum assignments, provided that their own use of spectrum is not compromised.

ASA provides a framework to enable sharing with a guaranteed quality of service (QoS) for both incumbent and prospective users and thus enriches the range of spectrum utilization options because, differently from other sharing models, it is based on a 'binary' form of sharing. That sharing is 'binary', means that any given portion of spectrum, defined in time and space, is used by either the incumbent or an ASA licensee. It is the incumbent who decides the terms upon which its spectrum may be used. In this sense, the ASA framework simply expands the incumbent's options, without jeopardizing existing spectrum use rights (including the right to refuse access).

The ASA licensee, on its part, may only use incumbents' spectrum on the terms decided by/negotiated with the incumbent. These terms are well defined in advance and therefore predictable for both the incumbent and the ASA licensee(s). Thus, on one hand, any ASA licensee may only deploy systems that prove to be non-interference compliant both against the incumbent and against the operation of any other ASA licensee in the same spectrum portion. On the other hand, ASA licensees enjoy spectrum rights of use that guarantee full protection from interference produced by the incumbent – as per the terms of the agreement – by other ASA licensees and/or by secondary users, which operate on a non-interference, non-protected basis. In other words, any ASA licensee enjoys the status of primary user as per ITU Radio Regulation definition (analogously to the incumbent), in those portions of ASA frequency bands that are not used by the incumbent spectrum user and fall within the agreement reached with the latter. In case of multiple ASA licensees within the same frequency band, each licensee enjoys the status of primary user when and where foreseen by the sharing agreement with the incumbent.

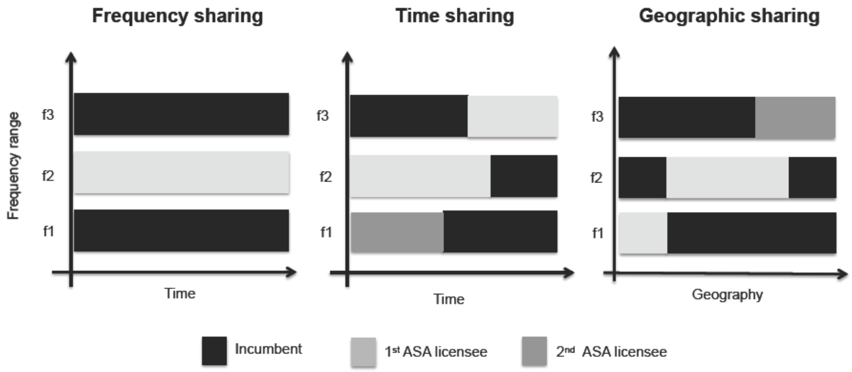
These features provide incentives to share spectrum under the ASA/LSA framework to both incumbents and prospective licensees. This is because incumbents may obtain compensation for the use of their spectrum, while prospective ASA/LSA licensees may obtain access to high-quality spectrum on predictable terms. This has been acknowledged by the RSPG, that has held that LSA has the potential of introducing appropriate incentives towards an efficient use of spectrum for both incumbents and new users, as it allows "better valuation of spectrum assets for the incumbent right holder when opening up spectrum for sharing".

Sharing agreements between incumbent spectrum users and prospective ASA licensees may foresee various arrangements. In particular, there may be: frequency-sharing, when the incumbent user only uses a subset of the available frequencies; time-sharing, when the incumbent user does not require to use spectrum continuously over time; and geographic-sharing, when the incumbent uses only a geographically limited portion of spectrum (see figure 1).

Moreover, sharing agreements may be long-term, short-term or scheduled, when they foresee sharing at specified and/or recurrent dates. Sharing conditions can also be fine-tuned according to counterparts' needs. For instance, they can be static, when there is a simple definition of the "exclusion zones" or "unused frequencies", or dynamic, when sharing conditions are defined according to real-time variations of parties' needs.

These features make ASA a tool suitable to increase the 'modularity' of spectrum usage, by allowing for a multidimensional decomposition of spectrum rights of use within a framework that preserves legal certainty and guarantees access to spectrum with a predictable quality. To do so, ASA/LSA relies on two main building blocks: a carefully defined regulatory/authorization framework and the use of database technologies.

Figure 1 - Spectrum sharing options



For concreteness, the salient features of the required regulatory framework will be described by reference to the European context. The ASA/LSA solution requires a number of administrative steps to be implemented in Europe. These steps are essential to guarantee international coordination of decisions of Spectrum Management Authorities and a predictable business environment.

The implementation of this novel policy tool requires, first, that ASA rights of use be clearly defined. In Europe, ASA rights of use definition would involve various institutions. The EU Commission may promote a harmonized implementation of the ASA framework through adoption of a Communication and an associated consultation. Technical harmonization measures aimed at identifying ASA candidate frequency bands and at clarifying common conditions for the use of ASA bands (e.g., band plans and non-interference rules) may be promoted by work within the European Conference of Postal and Telecommunications Administrations (CEPT) and standardization activities may be undertaken within the European Telecommunications Standards Institute (ETSI) and relevant Standard Development Organizations.

ASA rights of use would be awarded as individual rights of use by national Administrations, as per art. 5(1) of the Authorization Directive. This entails that national Administrations may voluntarily decide whether to adopt the ASA framework and that, in case they decide to do so, they are in charge of defining:

> "(i) the frequencies that can obtain an ASA status; (ii) the set of rights and obligations associated with each ASA licence; and (iii) the timeline upon which these rights and obligations remain valid. Finally, Administrations may be required to adopt ad hoc rules, as there may be very different kinds of ASA frequencies" (PARCU *et al*., 2012, p. 6).

Thus the awarding process of ASA individual rights of use would be analogous to the standard process of award of individual authorizations under the Authorization Directive, except for the fact that it would also foresee a sharing agreement between the incumbent and prospective user(s) of a given portion of spectrum. Only upon successful completion of negotiation with the incumbent spectrum user would any prospective ASA licensee be able to obtain a fully-fledged ASA license.

The existence of a clearly defined regulatory framework whereby incumbents agree to share their underutilized spectrum and Administrations designate the new use and define license award conditions for any given frequency bands within a harmonized framework sets ASA apart from traditional forms of subleasing or secondary trading.

The second key building block of the ASA framework is the use of database technologies. Database technologies enable to implement the form of binary sharing foreseen by the ASA framework because they allow to gather and manage information on: spectrum use by the incumbent; spectrum availability in the frequency/time/geographic dimensions, as defined by ASA rights of use and sharing agreements and QoS requirements. This information is then translated into commands to ASA licensees' base stations.

The above brief description of the ASA framework suggests that it nicely integrates existing complementary spectrum sharing models by combining elements of administrative, market-based and technology-based approaches to spectrum management. It relies on the comparative advantages of these different approaches, while limiting their weaknesses.

This new sharing model exploits the comparative advantage of the administrative approach with regard to the internalisation of externalities and coordination of the independent actions of multiple spectrum users, as it is a form of sharing based on individual authorizations. This means that cohexistence of different users within the same portion of spectrum is governed by strict ex-ante rules and technical measures, which define the set of rights and obligations that are binding for sharing partners and establish the technical requirements of the systems used, which have to comply with non-interference rules both against the incumbent and against other ASA licencees operating in the same frequency bands, according to the existing regulatory framework and to the agreement reached with the incumbent spectrum user.

ASA also fully exploits the flexibility afforded by market exchange, as it allows for sharing agreements to occur in a well-designed negotiating framework, which keeps transaction costs low, and provides incentives to reach an agreement to both incumbent and prospective spectrum users. At the same time, when adopted for non-commercial incumbent uses, it allows to escape sensitive questions as to the comparison of the value of monetizable and non-monetizable uses, since it does not displace existing uses.

Moreover, ASA is primarily enabled by database technologies that allow to exert adequate control over interference to respect the criteria specified in the contractual agreement. This generates new options for timely and dynamic sharing of assigned spectrum resources, increasing their productive exploitation by both incumbent and prospective users.

■ How does ASA/LSA compare to other sharing models?

ASA is not the only spectrum sharing model that has attracted attention in recent years. Sharing may occur through various combinations of administrative, market-based and technological tools, which give rise to the models listed below. The list does not exhaust the range of possible options, but provides an overview of the main solutions currently debated, highlighting their basic features in terms of the traditional categories of allocation [7], assignment [8] and application designation [9].

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[7] 'Allocation' refers to the definition (initial allocation) or modification (refarming) by national and/or international spectrum management authorities (SMAs) of the type of usage or technology for which a frequency range is identified. Allocations are made on a primary or on a secondary basis. Primary allocations grant to a given service priority in using the allocated spectrum and therefore protection from interference by services that use that spectrum on a secondary basis or on a primary basis but starting at a later date. Secondary allocations are not protected from interference from primary services and must not cause harmful interference to them.

[8] 'Assignment' (A2) refers to the identification of a specific spectrum right of use holder (e.g., a broadcaster, telecom operator, Ministry of Defence, etc.) by national SMAs. Assignment may be exclusive, and non-exclusive (shared).

Shared primary access (e.g., DECT and PHS [10]) occurs when multiple spectrum users are originally assigned individual authorizations that grant the same degree of protection from interference (multiple original assignees share the same spectrum portion).

Trading/leasing may enable spectrum sharing in a broad sense, when the holder of an original authorization to use a portion of spectrum asks Spectrum Management Administrations (SMAs) to transfer permanently (trading) or temporarily (leasing) usage rights over a sub-portion of spectrum to a different user upon compensation. In this case sharing normally occurs through a change in the initial assignment, implemented by the relevant SMA upon request of a single original assignee. In some countries it is also possible that, along with assignment, allocation and application designation is also modified following a contractual agreement among parties.

Collective use (e.g., WLAN, Bluetooth) is a model based on 'license-exempt' or 'unlicensed' access to spectrum, in the sense that users of any device that meets certain technical requirements may access spectrum without a specific authorization. It is often referred to also as a 'commons' or 'open access' spectrum management model (there is no original individual authorization or assignment).

Hybrid collective use (e.g., unlicensed TV white spaces) generally entails that holders of an individual authorization have the right to use spectrum on a non-interference basis, although they have to accept higher noise floors due to usage by unlicensed parties, who are entitled to use the band to the extent that they respect specified interference limits. In this case there is generally (though not always) an original individual authorization and a subsequent general authorization to use a portion of the licensed spectrum. Underlay and overlay technologies as well as databases may be used for management of unlicensed uses.

To understand these different sharing models, it may be useful to categorize them in relation to two features: (a) whether they foresee licensed or unlicensed use of spectrum (or both); and (b) whether they foresee

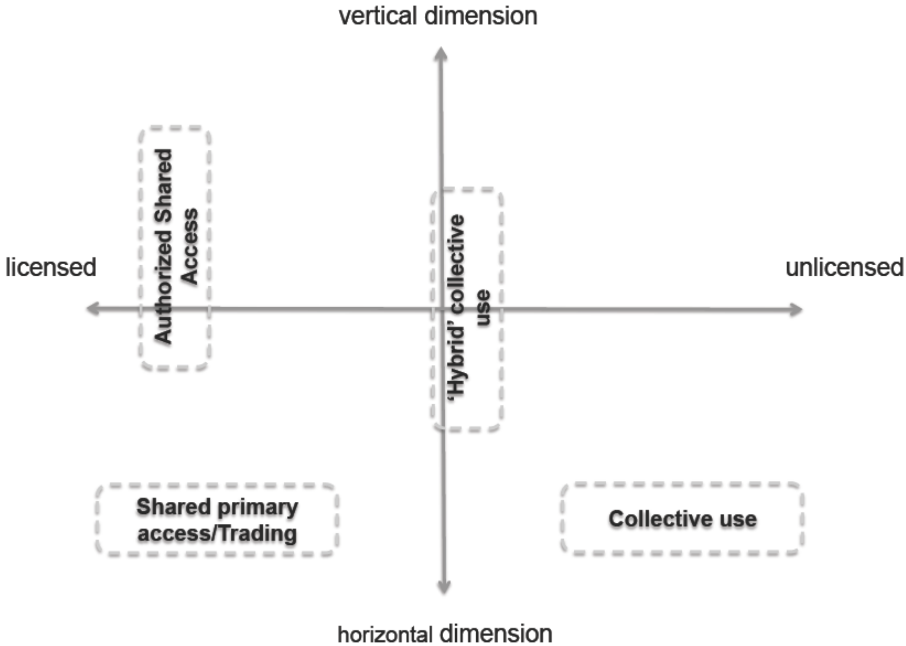
[9] 'Application designation' (A3) is the process through which policy makers designate a band for a more specific type of frequency use/application. For instance, a band allocated to mobile services may also be designated for use by IMT-2000 systems.

[10] Digital Enhanced Cordless Telecommunications (DECT) relies on cognitive technologies, and particularly on sensing. A DECT telephone uses an exclusively assigned frequency band but selects a frequency channel based on sensing of the channels available for that technology.

sharing along the vertical or horizontal dimension (or both). Vertical sharing refers to circumstances in which one of the sharing users has a higher level of authorization with respect to the other user(s) (and can therefore be defined as 'incumbent'). Horizontal sharing, on the other hand, refers to circumstances in which sharing users all have similar levels of authorization.

Figure 2 provides a visual representation of the different sharing models along the two dimensions described.

Figure 2 - Spectrum sharing models



The stylized representation of spectrum sharing models proposed in figure 2 is, of course, meant to capture the broad features of the different models so as to provide an intuition of the main differences among them. A more accurate picture should, indeed, recognize that all models may include some hierarchy of access. In the case of trading/leasing, there may be a vertical dimension if trades are conditional or if there are primary and secondary licensed users with tradable rights in a band. In the case of collective use, there sometimes are hierarchical elements, as for instance at 5GHz, when WiFi cohexists with radars. Moreover, it is important to stress that ASA, as mentioned in the previous section, realizes a peculiar form of vertical sharing, one that is binary in the sense that at any given point of time/geographic location, involves spectrum use by either the incumbent or the licensee, according to pre-defined sharing rules.

From a normative standpoint, it is possible to analyze the comparative properties of ASA relative to other sharing models in relation to four main criteria:

- ability to ensure effective management of interference,
- efficiency,
- degree of support to harmonization,
- transaction and implementation costs.

The first criterion is self-explanatory. The second – efficiency – is a multi-faceted criterion, as it is important to consider: allocative efficiency, i.e. ability of the system to ensure spectrum is destined to highest value uses; technical efficiency, i.e. intensity of usage as measured, for instance, by occupancy and data rate; and dynamic efficiency, i.e. the ability to enable long-term productivity increases through investment and innovation. The third criterion hints at the wide range of externalities that any model creates both across different jurisdictions and throughout the entire mobile value chain (mobile operators, content/service providers, handset/equipment manufacturers and, of course, consumers). Allocation and application designation choices made by a single country may not be able to deliver the desired benefits in absence of international harmonization efforts. A single national market may, indeed, be not large enough to attract investment in equipment and devices that match the chosen frequency allocation. Harmonization, by contrast, allows to free capacity for existing services, reduces network planning expenses for mobile operators and increases economies of scale in equipment and device manufacturing. This holds particularly when harmonization is functional to support adoption of a global standard such as IMT-2000. This generates positive feedback effects throughout the entire mobile ecosystem, resulting in lower prices and increased choice for consumers. Finally, it is important to consider also the transaction and implementation costs involved by the different models, both *ex ante* (such as, for instance, the costs of implementing the chosen model and the administrative costs of managing it) and *ex post* (in particular, the costs of enforcement and the costs in terms of legal certainty that may follow from the resolution of disputes concerning spectrum use).

Let us compare the four main systems of spectrum sharing already introduced according to the above criteria.

Trading

Sharing through trading/leasing has different characteristics in different countries. In some countries, trading enables changes along the three dimensions of allocation, assignment and application designation. In others, as for instance in most EU countries, it involves changes in assignment, but not in allocation and application designation. In both cases, since the usage rights of both incumbents and prospective license-holders are protected and license-holders may exercise full control over their assigned spectrum bands, within the limits set by regulation, interference may be adequately managed. Moreover, the possibility of voluntary changes in spectrum assignment through the market mechanism ensures in principle allocative efficiency by favoring the flow of spectrum to highest-value users and, to some extent, also technical efficiency. The ability to guarantee QoS through effective management of interference, in turn, preserves incentives to invest and therefore dynamic efficiency. However, for the benefits from trading/leasing to materialize, it is important that the regulatory framework allows to keep transaction costs to a minimum, which may be a difficult objective to achieve (CROCIONI, 2009). Moreover, even when transaction costs are sufficiently low, trading models that allow for changes in allocation and/or application designation may jeopardize harmonization, as the ability for authorized users to modify allocation increases spectrum segmentation. These limitations are possibly confirmed by the fact that the actual extent of trading has so far been more limited than expected.

Collective use / unlicensed sharing

CUS scores particularly well in terms of technical efficiency, as it enables access to spectrum to an unlimited number of users, thus maximizing the extent of spectrum utilization (FAULHABER & FARBER, 2003; BAUMOL & ROBYN, 2006; CAVE, DOYLE & WEBB, 2007). However, it should be noted that unrestricted entry does not guarantee allocative efficiency, since there is no effective mechanism to ensure spectrum utilization by the highest-value users. Moreover, technical efficiency is achieved at some cost in terms of ability to manage interference, since management of interference in absence of clearly defined usage rights is still imperfect given the present state of evolution of cognitive technologies.

As explained by the mentioned 2011 RSPG report on 'CUS and other sharing approaches', interference may be managed by introducing technical constraints, by limiting the type of applications that may be deployed (a restriction on the number of application designations) and through coordination among users. Economic theory shows that there may be great obstacles to recourse to the latter solution. The other two solutions pose immediate limits to flexibility (if a restriction to application designations is chosen) or may constrain flexibility in the long run (if technical limits are imposed). Moreover, as noted by the RSPG, flexible adjustment of spectrum policy by regulators may also be constrained by the fact that CUS may make it more difficult to clear bands due to the types of devices deployed.

Existing limitations in the management of interference, in turn, entail that CUS does not at present allow users to rely on a predictable level of QoS and involves limits to both the scope and scale of services that can be delivered to consumers and the remuneration for their provision. This suggests that CUS encounters some limits in terms of dynamic efficiency. On one hand, unlimited access to spectrum resources creates scope for experimentation and deployment of a vast array of applications, subject to a common set of technical rules. In particular, CUS tends to stimulate experimentation and innovation in low-power applications and niche markets based on fixed-to-mobile technologies. On the other hand, CUS does not appear to be well-suited to provide incentives to invest in expensive new technologies and stimulate large-scale investments in wireless broadband networks, when QoS is a significant concern to telecom operators.

CUS also shows some weaknesses as regards harmonization. Indeed, not only it does not provide an alternative to refarming, but it may even hamper harmonization if, to manage interference, bands have to be segmented by reducing the number of designated applications.

Finally, adoption of a CUS model entails significant implementation costs. Indeed, in a world where spectrum is already dedicated to valuable uses, CUS introduction requires existing authorizations to elapse or refarming (clearing or repurposing). The extraordinary refarming/re-purposing effort made in Europe can certainly be defined as a success story, showing regulators' ability to efficiently respond to market and consumers' needs by improving spectrum allocation and application designation. Refarming, however, is a painful process. If it is undertaken before expiration of existing licenses, it reduces rights certainty and gives rise to inefficient regulatory hold-up, with negative implications for incentives to invest. If refarming occurs only after expiration of existing licenses, on the other hand, it may not be able to timely address consumers' needs. More generally, refarming entails significant transaction and transition costs and therefore tends to take a very long time to be implemented. As a consequence, it also tends to be, by definition, backward-looking, as it mostly reflects past choices that require time to be implemented.

Thus, it appears that collective use of spectrum is most beneficial when specific circumstances apply, particularly when QoS requirements are not binding and the cost of unlocking spectrum for unlicensed uses is not too high. Collective use has, indeed, proved to be a viable and succesful model in some specific bands. The development of RLAN/WiFi systems has greatly benefited from the harmonization of the 2.4 GHz band and later from the 5 GHz band, which has allowed to support mobile broadband data offloading and fixed wireless connectivity on a best-effort basis. Similarly, the harmonization of the 863-870 MHz band for Short Range Devices in Europe has been key to the development of wireless services.

Hybrid collective use

Hybrid collective use (e.g., unlicensed use of TV white spaces) mixes individual authorizations and collective use along a vertical dimension. This model scores well in terms of technical efficiency, since it ensures an increase in the intensity of frequency bands utilization (albeit to a lower extent than CUS) through new entry by low-power devices.

As in the case of CUS, increased technical efficiency comes at a cost in terms of the ability to manage interference. The ability of the primary user to exercise control on interference is limited by the administrative imposition of band sharing, under specified conditions, with an unlimited number of users. Interference levels have to be fixed and controlled by SMAs, since this sharing model necessarily rules out the possibility of decentralized agreement over accepted interference levels. The number of potential unlicensed users is, indeed, too large to enable negotiation both vertically – between the incumbent user and unlicensed users – and horizontally – among unlicensed users.

The limited ability to manage interference has implications for dynamic efficiency. On one hand, incumbent users' ability to profit from the use of spectrum may be reduced to some extent, because in this case vertical band sharing with an unlimited number of users is administratively imposed, rather than voluntarily chosen. This, in turn, may reduce incentives to invest in efficient technologies. On the other hand, there are limits to the scope of new services that collective users may provide (and therefore to the extent of the investment they are willing to incur) due to the absence of guarantees in terms of control of interference and QoS.

This model raises similar concerns to CUS also in terms of harmonization, while it involves lower implementation costs as, to be implemented, it does not require changes in existing spectrum assignments. However, it involves a potential surge in *ex post* transaction costs associated to the disputes that may easily arise due to imperfect management of interference.

As a final note, it is worth emphasizing that, although this approach does not (yet) represent a ready-to-use solution from a technological and commercial standpoint, on-going research supported by many Administrations suggests its commercial application may be relatively quick.

ASA (Authorized Shared Access)

ASA scores well in terms of all of the evaluation criteria introduced above. The first relevant aspect worth noting concerns the ability to manage interference, which is surely greater than in the case of unlicensed sharing, due to the administrative set-up foreseen by the ASA model that is able to ensure predictable interference levels for both incumbent spectrum users and ASA licensees.

This greater effectiveness in interference management is obtained at the cost of a lower intensity of spectrum utilization and therefore lower levels of technical efficiency as compared to unlicensed or hybrid models, although the use of database technologies improves the intensity of spectrum utilization as compared to traditional licensing/leasing, by allowing for more 'modular' exchanges of spectrum usage rights.

For the same reason, ASA increases the liquidity of spectrum markets and therefore allows for substantial improvements in allocative efficiency relative to both traditional trading/leasing and unlicensed/hybrid models. Moreover, the opportunity to monetize unused spectrum resources through sharing while preserving QoS increases the opportunity cost of keeping spectrum idle. This allows to overcome some of the issues that have so far hampered the effectiveness of market-based mechanisms. In particular, it may alleviate the problems of spectrum capacity hoarding (for this and other anticompetitive behavior in spectrum markets, see CAVE, 2010), by introducing additional capacity. ASA may thus reduce entry barriers for both small scale users and users with greater spectrum requirements. At the same time, since under the ASA model both primary and secondary uses are licensed, and therefore paid for, both will tend to reflect the opportunity cost of spectrum (i.e., they will tend to flow in the hands of those with the highest valuation).

Increased dynamic efficiency is also a feature of ASA. Under the ASA model, both incumbent spectrum users and licensees enjoy a predictable level of interference and may therefore provide services of a guaranteed quality. Sharing occurs under a framework characterized by legal certainty and well-defined rights and obligations for all parties. This, in turn, provides a suitable environment to stimulate investment. Moreover, the modularity of spectrum sharing allowed by the ASA framework may also promote entry and investment by small scale users, allowing for splintering and experimentation in existing or emerging technologies and markets.

ASA scores well also in terms of transaction and implementation costs. This is primarily because it preserves existing spectrum allocations, assignments and applications designations, so that it does not require refarming or re-purposing. It is a process completely independent from refarming/re-purposing, as the latter is neither a pre-condition, nor the consequence of the implementation of the ASA model. At the same time, ASA will of course introduce some *ex ante* costs related to contract definition and database management costs (compatibility studies, set-up of the database, etc.). It will also introduce some *ex post* costs due to the need for some monitoring of ASA contracts. However, the fact that ASA licencees' uses are authorized reduces the scope for *ex post* transaction costs in the form of litigation and dispute resolution costs. In addition, it should also be considered that incurring the database and monitoring costs will also provide public decision makers with real-time and economically sound information on emerging efficient uses of spectrum.

Finally, perhaps the greatest benefit of ASA, as compared to the other models, resides in the extent to which it supports harmonization. Harmonization has the potential to generate positive feedback effects throughout the entire mobile ecosystem, resulting in lower prices and increased choice for consumers. For these benefits to materialize, however, harmonization should be flexible, so as to avoid introducing unnecessary rigidities in spectrum management, and this is precisely what ASA grants. ASA indeed supports harmonization by enlarging the options available to spectrum users (also in terms of application designation). Moreover, ASA is also flexible because, unlike traditional refarming, it allows to achieve harmonization while reflecting local spectrum management choices and policies.

In view of these features, ASA is applicable to any spectrum portion with unused capacity that can be shared. However, it is particularly suited for frequency bands currently destined to non-commercial uses under the control of a public entity (e.g., the military). It may allow to reap benefits across a broad range of frequency allocations, as long as there is some unused capacity. However, immediate application to bands identified to IMT [11] but not yet made available due to incumbent use will provide immediate and sizeable benefits, as it will enable timely availability of harmonized spectrum with a predictable QoS, unlocking the broad range of positive externalities throughout the mobile value chain generated by harmonization.

■ Future prospects

The ASA concept is rapidly gaining currency in a number of international fora. In the US, the Federal Communication Commission has adopted in December 2012 a Notice of Proposed Rulemaking on the 3.5 GHz band, which considers the implications of a version of the ASA concept alongside small cells deployment in the 3.5 GHz band, currently used by high powered Department of Defense (DoD) radars as well as non-federal Fixed Satellite Service (FSS) earth stations for receive-only, space-to-earth operations and feeder links [12].

The National Telecommunications and Information Administration has also shown interest for the possibilities opened by licensed forms of spectrum sharing.

Concrete steps towards ASA implementation have also been undertaken by the European Conference of Postal and Telecommunications Administrations (CEPT), which include 48 countries. CEPT has assessed LSA/ASA and drafted an internal report on the ASA concept. It has also created two ASA-related working groups (FM52 and FM53), in charge of

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[11] IMT stands for International Mobile Telecommunications, which is a set of 3G mobile standards approved by the International Telecommunications Union.

[12] http://www.fcc.gov/document/enabling-innovative-small-cell-use-35-ghz-band-nprm-order.

progressing towards the frequency harmonization work necessary to ASA implementation.

In the European Union, the European Commission has published a Communication on 3 September 2012, focusing on different spectrum sharing proposals that could provide incentives to market players and stimulate innovative investment [13].

The Communication considers the ASA/LSA concept as one form of sharing, even though it does not appear to have captured every nuance of the concept. In spite of this, in November the Commission issued a standardization mandate to the European Committee for Standardization (CEN), the European Committee for Electrotechnical Standardization (CENELEC) and the European Telecommunications Standards Institute (ETSI) to enable the deployment and operation of ASA devices [14] and has issued a Request for Opinion on Licensed Shared Access to the RSPG to further explore the scope for concrete application of the LSA approach [15].

Conclusions

In this paper we have investigated the rationale behind the licensed spectrum sharing model which has been named LSA/ASA. Our analysis concludes that LSA/ASA constitutes a new policy tool for spectrum management, complementary to existing and developing tools, to be fully exploited in order to face the risk of spectrum crunch.

The positive developments around this model should be further encouraged, in our view, for at least three reasons. The first is that including ASA in the regulatory toolikit, along with other complementary tools, may constitute a way to overcome, at least in part, the long-standing effects of the fragmentation of spectrum policies, both in Europe and in the broader international context. International coordination is key to enable ASA

13 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).

14 European Commission, Standardisation Mandate to Cen, Cenelec and Etsi for Reconfigurable Radio Systems, M/512, November 19th 2012.

15 European Commission, Request for Opinion on Licensed Shared Access (LSA), RSPG12-424 Final, November 8th 2012.

implementation and unlock the benefits from increased harmonization. Moreover, to achieve economies of scale in the design of consumer devices, technical harmonization measures have to occur on a supra-national scale. However, an important point about the implementation of this form of licenced sharing is that, while technical harmonization measures are indeed important, adoption of the ASA solution does not require extremely high degrees of international coordination, as different countries may adopt this licencing scheme to the extent and with the specific rules that they deem appropriate. The flexibility of implementation of the ASA model entails that underutilized spectrum may be made available in a shorter timespan than with other policies and incurring lower transition costs.

The second reason has to do with the ability of the ASA model to spur development of mobile broadband by releasing spectrum suitable for 3G and 4G technologies. In this regard, ASA adoption may go a long way towards shortening the timeline to make spectrum suitable for 4G available. This may occur, for instance, by applying the ASA concept to the 2.3 GHz band in Europe or to the 2.6 GHz band in Asian countries. Moreover, ASA may bring down the costs of mobile data networks, among other things because the specifities of the ASA model suggest that standard coverage requirements in the deployment of mobile data networks appear inapplicable to ASA spectrum due to the intrinsic restrictions present in the agreement between incumbents and ASA licensees. Finally, a spur to development of broadband networks (BELLOC *et al.*, 2012) may also come from the enhanced possibilities to access spectrum that ASA opens for small MNOs and MVNOs.

The third reason why ASA is a promising new model lies in the fact that it appears particularly suited to create incentives for innovation in different respects. From a technological point of view, ASA may provide incentives to invest in technological solutions that enable new uses of spectrum in a harmonized framework, including very low frequency bands applications such as Machine-to-Machine (M2M) and Internet of Things (IoT) devices. The reduction of barriers to entry opens the way to smaller players who can provide innovative services.

ASA may also stimulate service innovation, especially as regards e-health, e-education and other public e-services. This may be a byproduct of agreements between prospective ASA licensees and incumbent non-commercial users. For instance, in the 380-470 MHz band, currently used by the Ministries of Home Affairs or Interior to provide PPDR/PMR/PAMR communications, there is scope for ASA agreements that may provide for non-monetary compensations in the form of innovative broadband PPDR services in exchange for sharing of the spectrum assignment.

Finally, and perhaps most interestingly, ASA may create opportunities for innovation in business models that have not so far had the chance to be in place. The possibility, mentioned above, to adopt agreements that foresee non-monetary forms of compensations for the use of spectrum assigned to non-commercial users is one case in point.

Many other cases can be thought about. Intermediaries with a range of different business models may emerge. New players, such as infrastructure vendors, may become ASA platform operators. New bundles of data and services based on the use of ASA spectrum may well be commercialized.

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Annex

	Management of interference	*Efficiency*	*Harmonisation*	*Transaction / Implementation Costs*
Trading / leasing	****	***	?	?
	Fully predictable QoS for both incumbents and prospective users.	Market exchange promotes allocative efficiency and, to some extent, technical efficiency. Effective management of interference safeguards incentives to invest and therefore dynamic efficiency.	Depends on trading/leasing rules. Trading models that allow for changes in allocation and/or application designation may jeopardize harmonization.	Depend on design of trading/leasing framework.
Collective Use (CUS)	*/**	*	*	*
	Being unlicensed, there is no legal protection for sharing users. 'De facto' protection depends on technology. Risk of inteference and congestion.	Maximizes spectrum utilization and therefore technical efficiency. Does not ensure allocative efficiency. Dynamic efficiency limited by absence of predictable QoS for users, which hampers large-scale investment.	May create obstacles to harmonization if band segmentation is needed to avoid interference.	To be implemented, it requires existing authorizations to elapse or bands repurposing/refarming.
Hybrid Collective Use	**	**	*	**
	Incumbent users' QoS protected, although possibly slightly reduced. Unlicensed users' QoS not guaranteed.	Lower technical efficiency than in CUS, but higher than in other models. Absence of guaranteed QoS limits investment by unlicensed users and therefore dynamic efficiency.	Same as Collective Use	Implementation costs lower than CUS because it does not require changes in existing assignments. Scope for ex-post transaction (litigation) costs.
Authorized Shared Access (ASA)	****	****	****	**
	Fully predictable QoS for both incumbent users and licensees	Technical efficiency higher than in trading/leasing and lower than in CUS. High allocative efficiency. Dynamic efficiency promoted by investment by both small-scale users and users with greater spectrum requirements.	Provides an alternative to refarming. It enables flexible harmonization and can be adapted to local spectrum management policies.	Compatible with existing allocations and assignments, it does not require refarming. It implies some transaction costs for the design and monitoring of the required regulatory framework.