MIT Communications Futures Program

Toward More Efficient Spectrum Management

New Models for Protected Shared Access

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Executive Summary

There is general recognition that the growth of wireless services will require significant improvements in the utilization and management of scarce RF spectrum resources.

The need for expanded access to spectrum has been noted in a number of studies,[1] and addressing this need will require expanded use of shared spectrum in all of its myriad forms – whether managed by an operator in licensed exclusive-use spectrum, shared in an uncoordinated way in unlicensed spectrum, or under some other mixed sharing regime. What we need is a paradigm shift in how we manage spectrum access to enable a host of business models, technologies, and sharing regimes that collectively may be referred to as Dynamic Spectrum Access (DSA) systems.[2]

The genesis and primary focus of this paper is on a new emerging model for enabling DSA that includes sharing among multiple network operators, each with licensed interference-protected access rights. This model has variously been referred to as Authorized Shared Access (ASA),[3] Licensed Shared Access (LSA),[4] or Priority Access (PA).[5] What is novel in all of these is the addition of a new form of licensee with protected access rights that allow the new licensee to share spectrum with the incumbent licensee in a mutually, non-interfering way. The models differ with respect to whether other shared access, including unlicensed access, is also allowed in the band. Furthermore, when applied to specific bands, the models are further refined, leading to additional discriminating details. Finally, it should be noted that these models are evolving in real-time so much of the terminology and many of the details are in flux.

The ASA/LSA/PA model is one class of a range of regulatory frameworks for enabling DSA. Other concurrent initiatives include expanding unlicensed access to TV band (TVWS)[6] and 5GHz[7] spectrum.

While the technologies and standards needed to implement the ASA/LSA/PA model are under-development, commercialization of these and other sharing models confront additional business, market, and policy challenges. Collectively, we refer to the ASA/LSA/PA, and other shared spectrum models, as Protected Shared Access Models (PSAM). As with DSA, we use PSAM loosely to refer to the set of technical, business, and regulatory mechanisms and institutional arrangements that enable DSA.

The purpose of this white paper is to provide an introduction to some of the business and policy issues associated with advancing these new sharing regimes. Moreover, because these reforms are components in an overall effort to reform spectrum management practices involving many spectrum bands, what happens with respect to this model and other spectrum reform initiatives are closely related. Thus, the lessons being learned as we explore the ASA/LSA/PA model have wider and longer-term implications for spectrum sharing in the future.

Contents

1. Intended Audience, Purpose, and Acknowledgments

1.1. Intended Audience

The issues we address in this paper exist at the intersection of technology, economics, and policy. Since most readers will not have fluency across all these domains, some effort is made to explain concepts and background that may be well-known to experts in a given domain.

The intended audience for this paper are policy and business decision makers, researchers, and analysts in the wireless *supply chain* (radio system equipment and software providers, mobile content/application developers, wireless network service providers), the user community (represented by consumer advocates and enterprise customers), policymakers (regulatory authorities), and research community (multidisciplinary technical, economic, and legal/policy academic and industry researchers).

In referring to wireless services, we mean to include *all* users of the radio frequency spectrum (active and passive), whether they are using radios for communication services or sensing, and whether those radios are single devices or part of a multi-radio network. We will use the term Wireless Network Service Provider to refer to a licensed private or commercial entity that operates multiple access points to provide communication services over a wide coverage area. This includes cellular phone service providers, mobile wireless data service providers, and wireless Internet Service Providers (WISPs). Other potential commercial users/uses include point-to-point private lines, wireless backhaul, location specific medical telemetry, and public safety.

1.2. Purpose

The purpose of this white paper is to help illuminate active current discussions about important new models for managing shared access to radio frequency spectrum that are on-going in the research community, industry, and regulatory forums around the world, but with a special focus on the U.S. and Europe.

The pressing need to make available additional radio frequency spectrum resources to meet the requirements of the rapid growth in wireless services of all kinds lends urgency to these debates. The growth of commercial mobile broadband services and the ecosystem of smartphones and other increasingly capable wireless mobile device platforms, mobile commerce, and the mobile broadband Internet provide key drivers. At the same time, the need to upgrade the wireless capabilities of public safety, military, and other government users further complicates the picture.

Figuring out how to best make available new spectrum resources simultaneously engages complex multidisciplinary technical, business, and policy issues that strain the skills and knowledge of domain experts. Even for specialists who have been involved in spectrum management and wireless systems for many years, keeping

abreast of emerging technical innovations, changing regulations and legal frameworks, and rapidly changing wireless markets and businesses is difficult. This is an area rife for confusion and disagreements. Engaging these issues is often exceedingly daunting for newcomers but the issues are sufficiently important and with implications across the Internet and wireless economy that we need to broaden the basis of engagement.

The goal of this white paper is to highlight some of the key multidisciplinary issues associated with a new model for enabling shared spectrum access under active consideration by standards bodies and regulatory authorities in the U.S. and Europe. Hopefully, this will help foster communication and more informed cross-disciplinary discussion and provide a helping-hand introduction to those who may be new to the debates.

The specific issue chosen for focus for this white paper is a new model for enabling *protected shared access* to radio frequency spectrum. We italicize each of the terms to highlight that the definition of these terms and what they should mean are topics of debate. The origins of this work began with an effort to investigate what is variously referred to as spectrum sharing under the Authorized Shared Access (ASA), Licensed Shared Access (LSA), or PCAST/Priority Access (PA) models for sharing incumbent spectrum with a licensed secondary user, and potentially also with unlicensed users. Each of these terms is discussed further below.

1.3. Caveat to Reader regarding Coverage and Terminology

The models and associated terminology (e.g., ASA, TVWS, DSA, etc.) continue to evolve in real-time as industry stakeholders engaged in research, in commercializing technologies, and participating in standardization and regulatory forums continue to refine their thinking.

The potential confusion resulting from the fact that the technology, terminology, and policy proposals remain a moving target provides a daunting barrier for newbies to engage in these discussions. The goal of this white paper is to provide some insight that will help reduce the challenge of coming up to speed with the issues, but in so doing we have decided to err on the side of completeness. The views presented here and coverage of topics is neither comprehensive nor complete either in addressing all important topics or representing all views. Striving for a more comprehensive discussion would have further delayed publication. Waiting until the proposals or terminology were more settled would limit the value of this white paper to the current policy discussions.

1.4. Acknowledgements and a Note to the Reader

This white paper is a product of the MIT Communications Futures Program (CFP), which is a joint academic/industry research consortium focused on a series of multidisciplinary topics emerging in the Internet ecosystem. The CFP organizes itself in a series of working groups to engage topics of interest to the MIT researchers and their industry partners where our multidisciplinary expertise may contribute to mutual and enhanced understanding. By multidisciplinary, we seek to engage domain

experts in technology, economics, and public policy in academia and industry, and across the Internet value chain to address topics that are not otherwise well addressed by more typical silo-based research efforts.

More specifically, this paper is a collective product of the participants of the CFP's Spectrum Working Group ("SpectrumWG") that was organized with the leadership of Bill Lehr (MIT) to provide a forum for focused discussion within the CFP on issues at the junction of wireless technology, markets, and spectrum policy reform. The special focus for this group is the topic of shared spectrum access models for mobile communication services.

The participants in the SpectrumWG include academics from several institutions and industry participants employed by firms across the value chain and world. These participants do not always agree with each other, and participate as individuals rather than as representatives of their institutional homes or employers.

The substantive material presented in this white paper is presented as a series of "Q&As" that may reflect a narrow perspective. We do not attribute specific answers to specific participants, nor do we attempt to be comprehensive in our organization of the Q&As. However, we have endeavored to assemble a working group of knowledgeable experts representing diverse but not all-inclusive perspectives. The Q&As address issues that range in complexity from simple clarifying definitions to more abstract thinking about longer-term research questions and goals.

2. Introduction and Synopsis

2.1. An introduction to Terminology

This paper discusses a novel spectrum sharing approach that is being discussed in regulatory, industry, and standards forums in the U.S., Europe, and elsewhere. The approach is variously referred to as Authorized Shared Access (ASA),[8] Licensed Shared Access (LSA),[9] or Priority Access (PA).[10] When we wish to refer to that which is common in these models, we will use ASA/LSA/PA, ASA/LSA, or each separately when we wish to highlight the differences.

Because these proposals are evolving at different rates through technology and standards development processes applicable to different spectrum bands, and because the trade, engineering, and policy press are not always careful and may differ in their use of these terms and their interpretation, readers should be forewarned that there is no perfect consensus on what these terms mean, and even more importantly, what these models do or should imply.

These proposals are closely related to the general movement in spectrum management policy to enable new models for sharing spectrum among multiple wireless network operators that includes a range of other sharing models (e.g., TV white space[11] and unlicensed sharing in the 5GHz band[12]). These spectrum sharing models and the technologies that support them are sometimes referred to as Dynamic Spectrum Access (DSA). This includes a wide-range of radio access models and the associated (cognitive radio) technologies "by which a radio system dynamically adapts to select operating spectrum to use available (in local time-frequency space) spectrum holes with limited spectrum use rights."[13]

2.2. Understanding the Market Need for Shared Access

Mobile network operators are anticipating a 1000x increase in capacity to keep pace with the growth of aggregate and per-subscriber data traffic.[14] Increased investment in infrastructure (e.g, larger number of smaller cells) and more spectrally efficient technologies (e.g., LTE) can help meet this challenge, but we also need more spectrum resources for commercial access.

There are multiple policy frameworks for managing spectrum access. These include exclusive licensed spectrum, unlicensed spectrum, and various mixed models. Spectrum is shared under all of these models, but in different ways. In exclusive licensed spectrum, which accounts for most of the spectrum used by cellular operators, the licensee manages the sharing of spectrum resources on behalf of its customers. The licensee is protected from harmful interference from non-affiliated users. In unlicensed spectrum (such as that used by WiFi), spectrum sharing is uncoordinated and users have no right to claim protection from interference from other users with band-compliant radios. Mixed models include secondary usage overlays such as have been proposed for unlicensed access to TV band "white space" (TVWS) and underlays for low power radios such as Ultrawideband (UWB).[15]

In these models, the secondary users are allowed to access the spectrum so long as they do not cause interference to the primary licensee. With UWB, this is accomplished by operating at sufficiently low power to be indistinguishable from the noise floor. With TVWS devices, it is accomplished by identifying locations and frequency bands where secondary use will not result in interference to the primary licensees, the over-the-air TV broadcasters.

The focus of this white paper is on a still newer model for spectrum sharing that includes two or more tiers of users. The ASA/LSA model was originally developed for shared spectrum access with cellular operators in mind, and was designed to support two tiers of users: an incumbent user and secondary licensed user. In this model, both users have interference protection rights. This model may be expanded by also allowing a third class of users to share the band at times and locations where the incumbents and the ASA/LSA users are not using the spectrum. For example, the PCAST report recommended and the FCC proposed in its 3.5GHz NPRM, a three-tiered access model, that includes an incumbent user, an (interference-) protected Priority Access user (PA), and General Authorized Access users (GAA). The GAA users may access spectrum so long as they do not cause harmful interference to either the incumbent or PA users. The precise relationship between PA and GAA users is still in the process of being worked out.

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The primary motivating interest in this new model is as a framework for providing shared access to spectrum where the incumbent users cannot be moved (at least in the near term), but where the incumbent's usage leaves opportunities for others also to access the spectrum in complementary (mutually non-interfering) ways. The model is enabled by a suitable Spectrum Access System (SAS). The SAS may be consulted by radios seeking to use the spectrum to identify opportunities where such operation is permissible. The design of the SAS, including how dynamic it should be, how the SAS should be managed, and how the SAS would mange shared access in the band are all questions that are being worked out.[16]

This new model has special applicability to the context of opening government spectrum bands for shared commercial users. However, the long-term implications of developing this model will have much wider implications. For example, the technologies needed to manage such sharing will be useful in other Dynamic Spectrum Access (DSA) contexts, and will contribute to moving us closer to a world of more efficient, capable, and flexible radio system networks. Management of this DSA world will require development of a generalized SAS that will possibly include a mix of databases and radio sensing systems, as well as the business, market, and regulatory processes and institutional arrangements needed to support its implementation and management. Initially, it is likely that there will be band or market-specific (e.g., national or regional) SAS that are not closely coupled. Over-time, these SAS may be tied more closely together to provide for interoperability and expanded options for dynamic control.

The progress of this and other sharing models from technology development to enabling regulatory reforms to commercialization in global markets is necessary to

realize the desired transition to a more robust, capable, and efficient spectrum management and wireless ecosystem.

In today's world, we confront significant artificial spectrum scarcity. Many users are seeking access to additional spectrum resources that are either unavailable or too expensive. At the same time, there is significant spectrum that remains underutilized. In the future, we would like to live in a world where spectrum can be directed to its most efficient uses and where those uses change. Consequently, we need a spectrum management ecosystem that is capable of redirecting spectrum to new uses at a variety of time-scales – from the time scales of real-time services (as in LTE), but also at the time-scales required for infrastructure investment. Ideally, we want to meet the growth needs of established and emerging uses and users. Just as their uses, markets, technologies, business models, and investment plans differ, so too do their spectrum requirements. An appropriate spectrum management system would address the full range of wireless usage needs.

2.3. Progress toward implementing new protected access sharing

In the U.S. and Europe, a wide-range of standardization, regulatory reforms, and early commercialization efforts are underway, directed at expanding commercial access to shared spectrum and exploring the new Protected Shared Access Models (PSAMs).

Progress in developing the ASA/LSA/PA models is underway in several bands. Although the efforts are distinct, there is substantial overlap in stakeholder participation, issues considered, and shared learning. In Europe, the focus has been on the 2.3GHz band; whereas in the U.S., the focus has been on 3.5GHz and 1.7/2.1GHz spectrum. Moreover, because of its relevance to DSA more generally, it is worth considering the progress of efforts in the U.S. to expand shared access to 600MHz, and 5GHz spectrum. In the following sub-sections, we provide a status update on each of these.

2.3.1. Europe 2.3GHz

In Europe, significant progress has been made on refining the Licensed Shared Access (LSA) model. The European Parliament and the Member States approved the Radio Spectrum Policy Programme (RSPP) in March 2012 outlining a roadmap for wireless.[17] Since December 2012, the Radio Spectrum Policy Group (RSPG)[18] has been developing a response to the European Commission's request for an Opinion on spectrum regulatory and economic aspects of Licensed Shared Access[19] and launched a public consultation on this Draft Opinion[20] in June 2013. In this revised Opinion, the RSPG agreed on a revised definition for LSA:

> *"A regulatory approach aiming to facilitate the introduction of Radiocommunication 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 LSA framework, the additional users are allowed 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 authorized users, including incumbents, to provide a certain QoS".

The RSPG is relying on the technical expertise of The European Conference of Postal and Telecommunications Administrations (CEPT)[21] to assess ASA/LSA technical sharing requirements on specific bands. CEPT's Electronic Communications Committee (ECC) has been studying ASA/LSA since 2011. In November 2012, the European Commission issued a standardization mandate to the Standard Development Organizations (SDOs) CEN, CENELEC and ETSI,[22] requesting they develop reconfigurable radio system standards to enable ASA/LSA.[23]

In Europe, the focus for ASA/LSA has been on the 2300-2400 MHz band. This is a band that was identified for International Mobile Telecommunications (IMT) during the World Radio Conference in 2007 and is widely used for mobile broadband outside of Europe.[24] However, it remains unavailable for mobile broadband in Europe due to incumbents' persistent need to access the spectrum. As such, the 2.3 GHz band is the prototypical example of a band for application of the ASA/LSA model.

In October 2012, CEPT Work Group Frequency Management (CEPT WGFM) established two Project Teams FM52[25] and FM53[26] to study implementing ASA/LSA in the 2.3-2.4 GHz band, with responsibility for coordinating with ETSI. FM52 is responsible for drafting a new ECC Decision for mobile broadband in 2.3 GHz, while FM53 is responsible for general ASA/LSA studies including the analysis of ASA 'Levels of Guarantee' and of the regulatory framework for delivering ASA licenses, as well as the development of general conditions and band-specific technical/operational conditions for the implementation of the ASA concept.

The European Telecommunications Standards Institute (ETSI) also launched a parallel standardization process for ASA/LSA systems in May 2012. The ETSI Technical Committee Reconfigurable Radio Systems ("TC RRS") has been working towards standardizing the use of ASA/LSA to enable mobile broadband services at 2.3-2.4 GHz.[27] A technical report defining the criteria and operational features, especially spectrum compatibility issues, of ASA/LSA at 2.3 GHz is now complete. While the focus of this work in ETSI and CEPT has been on ASA/LSA in the 2.3GHz band, the concepts could readily be extended to other bands, including potentially 1.7 and 3.5GHz bands.

On the industry side, trade associations such GSMA[28] and Digital Europe[29] (DE, the European consumer electronics association) have also taken positions regarding the ASA/LSA definition. In particular, DE recently responded to the RSPG public consultation regarding its draft opinion on LSA. It encourages the RSPG to further advance its work, calling for a clear and stable definition of LSA based on a set of regulatory principles that will lead to investments and innovation.

The first spectrum sharing trial of the ASA/LSA model with a live LTE network operating in the 2.3 GHz band was demonstrated in Finland in April 2013. The trial was carried out by Finnish CORE+ consortium coordinated by VTT Technical Research Centre of Finland.[30]

2.3.2. U.S. 3.5 GHz Band for Mobile Broadband under ASA/LSA

In December 2012, the FCC initiated a proceeding to enable commercial access for use by small cells in the 3550-3650 MHz band (the "3.5GHz Small Cells NPRM").[31] This spectrum is currently allocated for use by Federal radar systems (e.g., naval radar) and other uses, but has attractive properties for use by commercial small cells.[32] Because small cell radios would operate at lower power, it is expected that these could share with radar systems and other Federal users without requiring large exclusion zones that would threaten the economic viability of commercial interest using the spectrum.

Following on the PCAST report,[33] the FCC proposed a 3-tier model: (1) Incumbent users; (2) Priority Access (PA); and (3) Generalized Authorized Access (GAA), and the current proceeding focuses on applying this model to 3.5GHz spectrum for small-cell use. The PA users will have protected access rights, but will have to avoid interfering with Incumbent users (government radars and FSS); while the GAA users will have no interference protection rights and will have to avoid interfering with incumbent and PA users.

The FCC's original NPRM elicited significant comments from stakeholders across the industry, raising a number of significant questions that are still in the process of being resolved. For example, there was a question as to whether cellular operators could acquire PA rights. Also, a number of commercial stakeholders, including Qualcomm, Nokia Solutions and Networks and several cellular network operators opposed including GAA access, arguing that such use would limit commercial interest in the Priority Access (PA) usage tier and introduced excess uncertainty and complexity in the proposed new band. These opponents of GAA, argued in favor of the ASA/LSA approach.

Based on its review of the initial round of comments, in November 2013, the FCC issued a follow-on set of comments on the proposed 3.5GHz licensing framework, that retained its proposal for GAA access and provided further direction as to its proposed plans for allocating PA rights.[34] Some of the areas where FCC thinking evolved in its subsequent comments included:

- Original NPRM did not recognize commercial wireless network service providers as potential PA users. Rather, PA was envisioned for public safety and health care user/uses at very low power levels. It is now clear that network mobile operators will also be able to use PA.
- Originally, there was no clear intent to sell or auction PA licences to raise revenue. It now seems likely that PA licenses may be auctioned on a geographic and bandwidth basis if demand outstrips supply.
- The revised framework allows SAS-authorized opportunistic access to the GAA tier with targeted exclusive access to the Priority Access tier. GAA users would be licensed by rule under Part 95, requiring registration with the SAS for operation as set forth in the NPRM.
- There is on-going consideration about flexibility in assigning channels for allocation, with the concept of all PA usage cases being assigned from a pool of channels that spans the entire 3.5 GHz band. In other words, there may be

no partitioning of the band into separate spectral sub-blocks (pre-defined frequency channel sub-block assignments), but rather PA bandwidth assignments to requesting PA license holders may be on any set of channels. This requires the PA radio sets (base stations and end user devices) be able to tune across the entire band. Similarly, sub-band front end filtering would not be feasible and it would not be able to protect PA devices with dissimilar air interfaces from one another through RF filtering. Importantly, this implies closer coordination of the rules in terms of power levels, antenna gains, TDD versus FDD, and time synchronization for TDD use.

- There is on-going consideration about consolidating the entire band, including both the 3500-3650 MHz and 3650-3700 MHz bands. Currently, there are some incumbent licenses for WISP operation in the 3650-3700 band. There is consideration that WISP operation may also be allowed in the 3500-3650 MHz band as well, also as a Tier 2 provider. This too expands the range of the radios.
- There is ongoing discussion on partitioning of the spectrum between PA and GAA users.
- There is ongoing discussion of what entity(ies) will manage the SAS system, and whether the management should be via one or more third parties.
- Many other details and rules are still under consideration.

In early January 2014, the FCC hosted a workshop to discuss the design for the Spectrum Access Systems (SAS) to be used to manage access to the 3.5GHz spectrum.[35]

2.3.1. US Allocation of AWS (1.7/2.1 GHz) Band

The Federal Communications Commission (FCC) notified the National Telecommunications and Information Administration (NTIA) that it plans to commence the auction of licenses in the 1695-1710 MHz band and the 1755-1780 MHz band as early as September 2014.[36] These two bands are currently allocated for Federal Government use. The National Telecommunications Information Administration (NTIA)[37] estimated that it would take 10 years and cost $18 billion to clear these bands for reallocation for commercial use.[38] These bands are of interest for pairing with other spectrum intended for use by commercial cellular broadband service providers.

The wireless industry proposed that the first of these bands, at 1695-1710 MHz (uplink) would be paired with 2095-2110 MHz (downlink) Broadcast Auxiliary Service ("BAS") spectrum, creating a new 15+15MHz paired band; whereas the second of these, at 1755-1780 MHz (uplink) would be paired with 2155-2180 MHz[39] (downlink) Advanced Wireless Service (AWS) spectrum, creating a new 25+25 MHz paired band. These new spectrum bands would effectively extend the current U.S. AWS band (1710-1755/2110-2155 MHz) by 2x15 MHz on the lower edge and 2x25 MHz on the upper edge.

The new extended band in the US, when made available, would overlap with the 1710-1770/2110-2170 MHz band,[40] which has been identified for IMT by the ITU

and consequently to be made available in many countries in the Americas. There is on-going work in CITEL[41] to extend this band by 10+10 MHz (1770-1780/2170-2180 MHz), which would help develop a regional ecosystem for AWS spectrum.

The U.S. Commerce Spectrum Management Advisory Committee (CSMAC),[42] which advises the NTIA on a broad range of spectrum policy issues, established five Working Groups (WGs) "to facilitate the implementation of commercial wireless broadband in the 1695-1710 MHz and 1755-1850 MHz band." The WGs have been deriving protection distances or exclusion zones for two interference scenarios: (1) Government system receiver as potential victim of interference from LTE UEs; and (2) Government system transmitter as potential source of interference to LTE base stations.

The initial analyses of system sharing in these bands resulted in excessively large exclusion zones. If adopted, these would preclude commercial use of the spectrum in many populous markets, threatening the economic viability of commercial use of the spectrum.

The WGs also identified a number of issues for follow-up work items, and identified ASA/LSA as a promising sharing mechanism that might be applicable to these bands, concluding that:[43]

> "Time-Based Sharing – Commercial wireless industry presented information on proposed innovative spectrum sharing techniques (e.g., time-based sharing or real time monitoring via Licensed Shared Access) that could exploit the advanced features in the LTE standards to enable use of spectrum assigned to government users without impact to operations. These mechanisms have the potential to facilitate sharing by enabling commercial wireless licensees to dynamically relinquish their use of the shared spectrum with minimal impact to users in areas during times that government users are using the band. The proposal did not include the implementation details and would need further study. Both government and industry interests writ large should work together to further study these approaches, sharing as much information as practicable about the systems that are envisioned to share using such mechanism, as well as the projected operational aspects and economically acceptable conditions, to determine feasibility of sharing without a negative impact to both government and commercial operations. This study should include the feasibility of the time-based sharing Licensed Shared Access regulatory construct. This study should also include the potential impact on government operations and proposed commercial operations in this band, and the implementation details on the real-time/near real-time information requirements for both government and commercial wireless licensees, whether it is via a database or some other secure means. Further, the study should consider the economic acceptability of the proposal."

This was further echoed in a letter from the Commercial Wireless Industry to NTIA:[44]

"Through a combination of sharing, relocation and channel prioritization for the majority of operations in the 1755-1850 MHz band it appears feasible to provide industry early access to the 1755-1780 MHz portion of the band. In some cases, additional analysis may need to continue to further refine long-term arrangements for the entire 1755-1850 MHz band, including potential long-term sharing in the 1755-1850 MHz band and/or other frequency bands as appropriate. The additional analysis could not only further refine the static exclusion zone sizes as needed but also develop innovative spectrum sharing techniques that exploit the more dynamic nature of the use of the spectrum and the advanced features in the LTE standards that we have started to discuss in CSMAC WG-5 in particular."

2.3.2. TV Band Spectrum at 600MHz and TVWS

Although the ASA/LSA/PA model has yet to be formally proposed for application in TV band spectrum below 1GHz, this has been a focus of efforts to clear and reallocate spectrum for higher value, commercial mobile broadband services for many years. Historically, a significant share of the prime spectrum below 1GHz has been allocated for over-the-air TV broadcasting. The reallocation of this spectrum for new digital over-the-air broadcasting or other services such as mobile broadband has been referred to as the "Digitial Dividend."

Of relevance to the present discussion, for over a decade, the FCC has been developing rules to enable DSA in TV bands.[45] This is commonly referred to as TV White Space (TVWS) access. Under this model, unlicensed TVWS devices would be permitted to access TV broadcast spectrum in certain bands when such access would not interfere with broadcast licensees. Management of the DSA by TVWS devices was to be via TVWS database system. The thinking behind the design and management of this spectrum access system has contributed to the thinking about the SAS to be used to manage spectrum in other policy frameworks, including ASA/LSA/PA. The FCC issued its most recent order in this proceeding in April 2012.[46]

Concurrently, the FCC is in the midst of developing to rules for repacking and clearing a significant share of the 600MHz spectrum as part of a complex two-part broadcast incentive auction.[47] This would be the largest auction ever held by the FCC and is currently scheduled for second half of 2015.[48] The outcome of this auction will have a significant implications on the availability of spectrum for TVWS devices and the future demand for and availability of DSA devices.

2.3.3. FCC 5GHz NPRM

The FCC is also currently engaged in expanding commercial access to spectrum in the 5GHz band that is also currently allocated for Federal use under an unlicensed access framework.[49] This proposal would open up 195MHz of spectrum at 5350-5470MHz.

Radios in this band would need to share on a secondary basis with Federal user incumbents and so represents another opportunity for DSA commercial system deployments. The commercial success (failure) of radios in this band would have implications for the commercial attractiveness of radios in some of the other bands noted above (e.g., 3.5GHz small cells, especially if operating as GAA radios, or TVWS devices in whatever spectrum may be available after the conclusion of the Broadcast incentive auctions).

3. What are the Protected Shared Access Models and why are they needed?

3.1. What are the ASA/LSA/PA sharing models?

ASA/LSA/PA sharing models, which we collectively refer to as Protected Shared Access Models (PSAM) are new ways of managing spectrum access that complements the existing models of licensed (exclusive use) and license-exempt (unlicensed) access. Much of the spectrum below 6 GHz is underutilized and could be shared either in time, geography, and/or frequency. In many cases, this spectrum is not used across an entire nation on a 24/7 basis—the spectrum is unused in various geographies and/or at various times. The PSAM framework identifies a way to allow one or more tiers of shared access that may co-exist with the incumbent users in a non-interfering way. Expanding access in this way provides a framework for enabling the "white space" that exists in such spectrum under the current access regime to be used more efficiently on a 24/7, nationwide basis.

Under the ASA/LSA/PA regime, spectrum rights are granted to licensees subject to the terms defined by the relevant authority (government, regulator[50]) with due attention paid to existing usage and access rights of the incumbent users. ASA/LSA/PA licensees use the spectrum for mobile broadband on a shared and non-interference basis with the incumbents. What is novel is that both the incumbent and ASA/LSA/PA licensee have interference-protected access rights to the spectrum.

There may be one or several such ASA/LSA/PA licensees in any given band since ASA/LSA/PA rights for a band may be awarded in more than one geographic region, in more than one set of frequency assignments, or in more than one set of total bandwidth assignments, depending on the usage of the incumbent. A key feature of ASA/LSA/PA is that it allows offering a predictable quality of service for the Incumbent as well as for the ASA/LSA/PA licensee when each has exclusive access to that spectrum at a given location at a given time. ASA/LSA/PA rights can be granted on a short or long term basis.

The ASA/LSA/PA models allow commercial access to spectrum that cannot be cleared from incumbent users at least in the near-term. Those incumbent users may be government or other commercial systems with only sparse usage requirements. Where preexisting uses are sparse (with respect to bandwidth use, temporal use, or on a geographic basis), the spectrum is under-utilized and shared access may be feasible. Some of the commercial uses that might find such shared access attractive include the following:

- Wireless Network Service Provider (WNSP) for cellular phone services or mobile wireless data services;
- Wireless Internet Service Provider (WISP) for fixed (non-mobile) internet access;
- Commercial point-to-point or wireless backhaul service;
- Hospital-based Wireless Medical Telemetry System (WMTS);
- Local area Wireless Public Safety Network (WPSN);

- Or other users needing interference-protected license guarantees for accessing the spectrum.

The ASA/LSA model was originally proposed in Europe; whereas the PA model is associated with the U.S. PCAST report and the FCC's proposed sharing plan for small cells in the 3.5GHz band. The ASA/LSA model differs from the PA model in that the latter also anticipates that there will be General Authorized Access (GAA) devices approved for opportunistic spectrum usage in the band. These GAA users would not have licensed interference protection rights.

Consistent with other unlicensed models, these GAA devices would operate at lower power. These GAA devices may either operate as unlicensed or "licensed by rule" (considered valid for use if the hardware is type accepted and meets the specified technical rules). The intent is to facilitate access to wireless products or services similar to unlicensed WiFi access. Besides the power level and technical rules differences, the biggest difference for GAA use is that it is not within a controlling network, but rather represent an individualized, uncoordinated 'Access Point' more similar to a WiFi access point. Thus the GAA deployed air interface may not have a defined control plane as most networked wireless air interfaces have. One key challenge for adoption of GAA is how to control and coordinate these access points and their end user devices from the ASA/LSA/PA system without the intrinsic control mechanisms for channel selection that most wireless networks do provide. It is expected that the ASA/LSA/PA system will use Internet access and a centralized ASA/LSA/PA manager to control the channel allocations for GAA devices. This technical framework for GAA control is not yet fully defined. The ASA/LSA model does not initially provide for such unlicensed use but the ASA/LSA centralized database could be expanded to allow GAA to check availability of the spectrum for use in a more opportunistic manner.

Also, most proponents of ASA/LSA/PA systems propose a centralized database mechanism to control spectrum allocations. The locations of all users in all tiers would be known, a distance based propagation model calculator would be used to determine nearest distance co-channel operations, and the ASA/LSA/PA manager would allocate spectrum accordingly. This is in contrast to many DSA systems, where the user's radios include a spectrum sensing receiver that is used to 'sniff' the shared spectrum and determine which channels are not occupied, and then autonomously choose to use them in order to avoid interfering with others. ASA/LSA/PA systems specifically prohibit autonomous decisions on the part of Tier 2 (and Tier 3) users and their equipment. Also, so far, it is not yet proposed to require that any of the devices (Tier 2 or Tier 3) be equipped with sensing capabilities, where they could report detected channel usage back to the Spectrum Access System (SAS). Spectrum sensing is made complex by the fact that the other Tiers of users are using different air interfaces, so that the sniffing receiver may not simply use its own conventional communications (operational) receiver to sense the other type(s) of waveforms. One could also imagine that GAA users could be allowed to access the database to determine when and where incumbents and ASA/LSA/PA users are not using the spectrum so that they can use it in a more opportunistic manner. This

would be an adaptation of the original ASA/LSA framework to take into account the expectation that the U.S. will adopt a 3-tiered framework that includes GAA.

3.2. Why do we need an additional authorization mechanism?

Regulators around the world are facing significant challenges in making spectrum available to meet the exponentially growing market demand for spectrum by all wireless services, and especially for mobile broadband services.[51] Indeed, the telecommunication industry anticipates significant wireless data usage increase. Wireless networks are expected to need to cope with up to 1000 times more data traffic over the next ten years. There is no question that far more spectrum is needed to keep pace with this exploding growth in demand.

Some countries have attempted to use market forces to overcome the problem of strictly static spectrum assignments by incorporating tradable property rights in frequency authorizations. In practice, however, the volume of trades has either remained low or has been restricted to the exchange of regional licenses. Thus far, such secondary market activity in spectrum usage rights has done little to alleviate spectrum scarcity.

There is also significant interest on clearing and reallocating spectrum from low to higher value uses. An example of this includes efforts to reallocate TV band spectrum to commercial broadband and to expand access to Federal spectrum. However, clearing spectrum is expensive and not always feasible in the time frame needed to meet commercial demand. Moreover, allocating spectrum for exclusive use licenses is unlikely to be sufficient to meet all demand for commercial access rights.

There is no single model for managing shared access to radio frequency spectrum that is best for all user/usage/market contexts. Consequently, the toolbox of spectrum management regulatory frameworks, or equivalently, authorization mechanisms needs to have multiple options.

The ASA/LSA/PA models discussed herein addresses a gap in existing frameworks, providing an intermediate model on the continuum from cooperative to non-cooperative sharing, from exclusive-use primary to pre-emptible secondary use.

Historically, there have been two basic paradigms for providing commercial access to spectrum: (a) Exclusive use; and (b) Open/commons or unlicensed. Under the former, the exclusive-use licensee has a right to exclude other users (i.e., Tx); while under the latter, no user possesses such a right. The "right to exclude" provides a mechanism for protecting against potentially harmful interference from other radio systems operating in the licensed spectrum. In contrast, users under the open/commons/unlicensed framework must tolerate potential interference from other users in the band. The "right to exclude" facilitates better control and predictability over spectrum quality, a desirable feature for many business model/market/technology contexts.

Most cellular and mobile data services are offered under exclusive-use spectrum licenses. The larger cell sizes, wide-area coverage, and need to support quality-sensitive services like fast-mobile voice that characterize the typical cellular mobile service business model place a high economic value on having increased certainty and control over the quality of the spectrum in the operator's coverage area.

In contrast, the unlicensed model has worked well for the popular WLAN technology WiFi because the typical deployment model is in small, singular, isolated cells where the need to manage the potential for interference from other radio systems is much less important and there is no need for handover coordination and network management of frequency allocations and resources. Each access point stands alone. Also, there is no separate 'control' plane identified, as all the air interface decisions and air interface management (channel usage decisions) are localized to the access point. There is no cooperation with other access points.

Both of these extreme frameworks enable spectrum to be shared but in different ways. The exclusive-use framework gives the primary licensee strong control over usage and allows a mobile operator fine-grained control over how to best share their spectrum resource with its retail customer pool (i.e., handset owners who share the spectrum with other customers of the mobile provider). The exclusive-use licensee may also sub-lease the spectrum to other service providers in time or geographically demarcated blocks, providing yet another way to manage spectrum sharing. Because the primary licensee retains unilateral control (under the terms of the license) to manage how end-users or other operators access the spectrum, we may view both of these models as forms of *cooperative* (controlled) sharing.[52] In contrast, the unlicensed model of spectrum access, including that used in dedicated unlicensed spectrum (such as the ISM bands used by WiFI) or in overlay (e.g., TVWS) or underlay (e.g., UWB) secondary use unlicensed spectrum, the sharing among such secondary users and between secondary and primary users is typically *non-cooperative (uncontrolled)*.[53] It is important to note that in areas of relatively sparse usage, *non-cooperative* (uncontrolled) sharing can be more efficient as there is no overhead of relaying control information. As the usage rate increases, however, the '*collide and retry*' interference mitigating strategies become less efficient, until the fully controlled (*cooperative*) models become more efficient. At very high use densities, the uncontrolled (*uncooperative*) methods break down and become untenable, as the collision interference dominates.

The ASA/LSA/PA frameworks provide a way for a new class of spectrum-quality *protected* user(s) to share the spectrum in a tiered manner, with lower tiers acting *cooperatively* to the higher tiered users above them, and acting *non-cooperatively* (pre-emptively) to the lower tiered users below them.

3.3. What are the differences between ASA/LSA, and PA concepts?

3.3.1. Priority Access (PA)

The United States PCAST report (June 2012) identified a three-tiered rights model that might prove useful for commercial users to share spectrum with government

incumbents. Obviously, the general outlines of the model could be applied in other sharing contexts, but the focus of the PCAST report was on government spectrum. The PCAST report identified the 3.5GHz band that was targeted by the NTIA "Fast Track" report (October 2010) as a good candidate band for early efforts to share government spectrum. The FCC's 3.5GHz proposed rulemaking specifically focused on the 3.5GHz band occupied in the U.S. by government radar systems and Fixed Satellite Services (FSS) as a candidate for the three-tiered model.

The three tiers identified by the FCC are (1) Incumbent users; (2) Priority Access (PA); and (3) Generalized Authorized Access (GAA), and the current proceeding focuses on applying this model to 3.5GHz spectrum for small-cell use. It proposes a "license-by-rule" approach for PA and GAA users which will include small cell deployments (within buildings and in small outdoor areas like stadiums or localized metro areas). The PA users will have protected access rights, but will have to avoid interfering with Incumbent users (government radars and FSS); while the GAA users will have no interference protection rights and will have to avoid interfering with incumbent and PA users.

3.3.1. Authorized Shared Access (ASA)/ Licensed Shared Access (LSA)

Licensed Shared Access (LSA) is the term of art adopted by the European Union in its discussion of this new type of sharing regime. It is discussed in the RSPG (2011) report.[54] Authorized Shared Access (ASA) is an analogous term.[55] ETSI has been working on standards to implement ASA/LSA in the 2300-2400MHz band. ASA/LSA will use WWAN radio access technologies. In particular, ASA can start using LTE 'out of the box' Release 8 for the radio access. On the device side, there will be no special impact beyond implementing the support of any ASA frequency band.

Access to shared spectrum under ASA is managed by the ASA controller. Its main function is to control the access to the spectrum made available to the ASA licensee based on rules built upon ASA rights of use and information on the incumbent's use provided by the ASA Repository. The controller retrieves information about available ASA spectrum from the ASA Repository through a secure and reliable communication path and propagates the permission or interdiction of use of ASA spectrum to the radio access network (RAN). The ASA Controller may be managed by the ASA licensee(s) or a trusted third party.

The ASA/LSA regime also uses a repository which contains the relevant information on spectrum of the incumbent available for use by the ASA/LSA licensees or even by GAA users in an expanded version (in the spatial, frequency and time domains). This repository would relate to the database that the FCC is proposing in 3.5GHz. It may add safety margins and deliberate distortions to the free spectrum in order to mask the true activity of the incumbent. Due to the sensitive nature of the incumbent's information, in some cases the repository would be country-specific and under the purview of the NRA (National Regulatory Authority). The ASA Repository may be directly managed by the Administration, the NRA or the incumbent, or be delegated to a trusted third party.

3.3.2. Key Difference between the ASA/LSA and PA Approaches

An important difference from the PCAST and FCC 3.5GHz three-tiered SAS and the ASA/LSA framework is that the ASA/LSA proposal does not explicitly anticipate that there will be GAA usage. Thus, ASA/LSA was developed as a two tiered model, with only licensed users. However, as pointed out previously, the ASA/LSA repository or database could be used by GAA users as needed to check on spectrum usage.

3.4. Compatibility of ASA/LSA/PA with regulatory frameworks

The ASA/LSA/PA framework is compatible with evolving regulatory frameworks in Europe and the U.S.

In Europe and in LTE standardization efforts, significant progress has been made in enabling the ASA/LSA model in the 2.3GHz band. Additional work is still required on European technical harmonisation, EU regulatory ASA/LSA/PA guidelines and national implementation measures. Member States, the European Commission, the European Parliament and CEPT will therefore each have a role to play in the definition and implementation of ASA/LSA/PA. There are already activities in CEPT and ETSI on ASA/LSA.

In the U.S., the focus for this model is on the 3.5GHz band, and potentially, also the 1.7/2.1 GHz bands.

4. Implications of ASA/LSA/PA for Spectrum Management

4.1. Will ASA/LSA/PA replace the need for new exclusive spectrum?

The ASA/LSA/PA model is not a replacement for exclusive licensed spectrum. MNOs believe "exclusive access through appropriate market-based licensing should remain the main regulatory approach for mobile broadband spectrum," but have endorsed expanding the models for managing spectrum to include PSAM as a helpful addition.[56] The excusive-use licensed model is compatible with MNOs long-term investment horizon and their need to secure predictable access to a critical mass of spectrum resources. MNOs regard the ASA/LSA frameworks as complimentary but imperfect substitutes for exclusive-licensed spectrum. The PSAM frameworks allow sharing among multiple classes of users (incumbents and ASA/LSA/PA licensees) which each have interference protection rights that may be asserted in their shared portion of the spectrum. The MNOs view the ASA/LSA frameworks as useful for expanding access to spectrum resources that with existing incumbents that cannot presently be made available for exclusive-use licensing. Such expanded access is needed to expand capacity and coverage and to mitigate the pressures of exponential traffic growth and the scarcity of spectrum.

4.2. Is ASA/LSA/PA about Mobile Network Operators sharing spectrum among themselves or their spectrum with third parties?

ASA/LSA/PA is not about Mobile Network Operators sharing spectrum among themselves. Such sharing is already feasible under existing frameworks for leasing and secondary market trading. For the purposes of the ASA/LSA/PA framework, MNOs would not be considered incumbents, but rather would be accessing either as new ASA/LSA/PA licensees in the band, or as GAA users (under the PA framework).

4.3. Does the ASA/LSA/PA framework allow both the incumbent(s) and the ASA/LSA/PA licensee(s) to enjoy a predictable quality of service in the use (and control) of the spectrum?

The ASA/LSA/PA framework allows both the incumbent(s) and the ASA/LSA/PA licensee(s) to enjoy a predictable quality of service when each is using the spectrum. Ensuring this mutually predictable interference protection is the key feature of this new framework. The ASA/LSA/PA licensee has full rights of interference protection from any intentional or unintentional interference regardless of source. This distinguishes ASA/LSA/PA from a legacy models for secondary use, where no such interference protection is made available.

4.4. What are the benefits of ASA/LSA/PA over using unlicensed spectrum sharing?

The exclusive licensed, unlicensed, and ASA/LSA/PA regimes are complementary, and all three are important tools for regulators to efficiently manage scarce spectrum resources. Each regime has distinct advantages in different market contexts. For

example, exclusive licensed spectrum has been important for operators of wide-area networks such as cellular networks that need to ensure predictable quality-of-service and 24/7 availability, potentially over national coverage areas. Unlicensed spectrum has been useful in deploying isolated base stations for use in wireless LANs, for cordless phones, and other local wireless devices. The ASA/LSA/PA model enables potentially both protected (like exclusive licensed) and unlicensed access in bands where an incumbent operator (also with protected access rights) continues to operate.

4.5. How does ASA/LSA/PA differ from TVWS?

ASA/LSA/PA licensees have interference protection, whereas TVWS devices are unlicensed. In both cases, the radios share the spectrum with other users. However, the ASA/LSA/PA licensee has exclusive rights over their licensed access to the spectrum. In contrast, any user of the TVWS may have to share the spectrum concurrently with an unlimited number of users. In other words, TVWS access points can overlap in coverage and collide with one another. And, users of the TVWS have no protection from interference.

4.6. What's the benefit for the existing spectrum rights holders?

Adoption of the ASA/LSA/PA model provides a way to enable access to under-utilized spectrum without requiring incumbents to vacate the spectrum. Enabling such co-existence can avoid having to incur the costs of relocating incumbents, or even when such relocation is eventually considered, can facilitate better cost management. Moreover, ASA/LSA/PA can open up cooperation and business opportunities, in a number of forms, between ASA/LSA/PA licensees and incumbents (e.g. public safety and commercial operators can share spectrum and infrastructure), thus creating incentives to make spectrum available under an ASA/LSA/PA regime.

5. Economic Implications for markets, industry structure, and competition

5.1. Socio Economic impact of the LSA/ASA

A number of studies have projected significant benefits of expanded access to mobile broadband services, and more specifically, the benefits of expanded access to the spectrum resources needed to facilitate the growth of wireless services of all kinds. Those benefits will be realized in terms of increased economic growth, job creation, and expanded consumer surplus. For example, the FCC (2010) estimated that adding 300MHz of new commercially accessible spectrum by 2014 had the potential to add in excess of $100 billion over the next five years.[57] Other analysts, have pegged the benefits of expanded wireless services even higher.[58]

While most analysts concur that the future benefits of mobile broadband are significant and that additional spectrum resources in multiple management frameworks are needed, they do not concur as to the regulatory regime that will offer the highest value. Moreover, because the implementation of the PSAM framework remains a work-in-progress, there are not many estimates of the potential value that might be realized. An exception is a recent economic impact study that was undertaken by GSMA on behalf of the MNOs. This study seeks to estimate the benefits of expanded access to spectrum under the LSA/ASA model in the U.S. at 3.5GHz and in Europe at 2.3GHz, under the assumption that the value is highest when the LSA/ASA framework most closely approximates the regulatory and technical conditions of exclusively-licensed spectrum.[59]

Proponents of unlicensed or alternative shared access models may reasonably question these estimates, arguing that shared or unlicensed use may actually produce higher economic benefits (contrary to the assumption embedded in the GSMA study.[60] It is not the purpose of this white paper to resolve such disputes, but to highlight both the apparent consensus that large socio-economic gains are at stake and that additional research and debate is needed before we may agree on how best to realize those gains.

5.2. What are the implications of ASA/LSA/PA in terms of competition?

The introduction of ASA/LSA/PA should be pro-competitive. As more spectrum is made available through ASA/LSA/PA licenses, existing and new players can offer innovative broadband services at an lower cost; consumers will be empowered and enjoy more choice among innovative business models, new services, and a wider selection of devices that best meet their needs.

5.3. What new business models do you expect will be enabled by ASA/LSA/PA sharing?

ASA/LSA/PA creates a new paradigm for a multiplicity of business models and services that have yet to be thought of. Particularly promising could be many forms

of sponsored connectivity. This may include the development of services/applications from wireless health to education, from machine-to-machine to improved coverage.

5.4. Do you expect new entrants in competition with existing telcos as a result of ASA/LSA/PA adoption?

ASA/LSA/PA is not about existing operators versus newcomers. By allowing the release of more spectrum in a given market, ASA/LSA/PA provides the opportunity of introducing more competition, as well as providing additional capacity and new revenue streams for existing mobile network operators. ASA/LSA/PA will also offer the opportunity for new players to compete in the wireless space. ASA/LSA/PA allows the market forces to lead towards the most commercially successful and socially beneficial use.

5.5. Does ASA/LSA/PA disrupt operators' business models?

ASA/LSA/PA will be an enabler both of new business models and expansion of existing business models. Economic forces, not government fiat, will decide who takes advantage of the opportunities that ASA/LSA/PA will create. Operators will have a great opportunity with ASA/LSA/PA to sustain their investments and to open new areas of innovation and to experiment those new business models. New entrants will likewise have a great opportunity to start new businesses based on SAS. It is the market that will decide who prevails.

5.6. Will ASA/LSA/PA be a threat to traditional Mobile Network Operators?

ASA/LSA/PA will present opportunities for existing Mobile Network Operators to extend capacity and coverage and for generating new revenue streams on a competitive basis. Each MNO will have the opportunity to decide whether to take advantage of ASA/LSA/PA and, if so, how. Expanding access to via ASA/LSA/PA will help reduce disparities across operators with asymmetric exclusively licensed spectrum holdings.

5.7. What about the use of sensing?

The ASA/LSA/PA model does not require that devices be able to sense their spectrum environment. However, enabling such capabilities is compatible with the framework and could be incorporated in the Spectrum Access System in the future.

Today's focus is on relying principally on a data base to manage spectrum access. A data base access method precludes local autonomy in selecting which frequencies are available for use, thereby giving the ASA/LSA system tight control of allocations and spectrum management. Although ASA/LSA will not require sensing, spectrum sensing could be added as an augmentation to make the database more dynamic and to take advantage of the additional information that sensing would provide. For an LSA/ASA system, sensing would provide a 'closed loop' method to update the controller's interference assessment model over time, without requiring separate drive testing to make measurements. Unlike some DSA and TVWS systems, it is not

proposed to use local spectrum sensing to allow autonomous channel selection without a connection and guidance from the LSA/ASA system.

6. Links to Other Sources and Materials

- NTIA, An Assessment of the Near-Term Viability of Accommodating Wireless Broadband Systems in the 1675-1710 MHz, 1755-1780 MHz, 3500-3650 MHz, 4200-4220 MHz, and 4380-4400 MHz Bands (rel. October 2010) (Fast Track Report), *available at:* http://www.ntia.doc.gov/files/ntia/publications/fasttrackevaluation_11152010.pdf
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7. Appendix 1: Working Group Participants

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[2] The IEEE P1900.1 standards Working Group (see http://standards.ieee.org/develop/project/1900.1.html) recognizes DSA as an umbrella term for a host of technologies and spectrum usage models that envision more dynamic spectrum access (in local time, geo-, and electro-space). This includes (but is not limited to) cognitive radio and related technologies. The need to define these terms more precisely is driven by standardization efforts and the need to tie together what previously has been a range of disparate R&D activities. Here, we use "DSA" loosely to refer to any technical/market/policy mechanism for sharing spectrum dynamically among users, uses, and/or networks in electro-space.

[3] Parcu, P., A. Nicita, G. Corda, M. Rossi, and L. Bravo (2011), "Authorised Shared Access (ASA): An Innovative Model of Pro-Competitive Spectrum Management," May 1, 2011, available at SSRN: http://ssrn.com/abstract=2174518.

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[6] Third Report & Order, In the Matter of Unlicensed Operation in the TV Broadcast Bands (ET Docket No. 04-186), Additional Spectrum for Unlicensed Devices Below 900 MHz and in the 3 GHz Band (ET Docket No. 02-380), Before the Federal Communications Commission, Released April 12, 2012 ("FCC TVWS 3rd R&O (April2012)"), available at: http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-12-36A1.pdf.

[7] Notice of Proposed Rulemaking, In the Matter of Revision of Part 15 of the Commission's Rules to Permit Unlicensed National Information Infrastructure (U-NII) Devices in the 5 GHz Band, Before the Federal Communications Commission, ET Docket No. 13-49, released February 20, 2013 ("FCC 5GHz NPRM"), available at: http://transition.fcc.gov/Daily_Releases/Daily_Business/2013/db0220/FCC-13-22A1.pdf

[8] Parcu, P., A. Nicita, G. Corda, M. Rossi, and L. Bravo (2011), "Authorised Shared Access (ASA): An Innovative Model of Pro-Competitive Spectrum Management," May 1, 2011, available at SSRN: http://ssrn.com/abstract=2174518.

[9] RSPG (2011), "Report on Collective Use of Spectrum (CUS) and other spectrum sharing approaches," Radio Spectrum Policy Group (RSPG11-392 Final), November 2011, available at: http://rspg-spectrum.eu/_documents/documents/meeting/rspg26/rspg11_392_report_CUS_other_approaches_final.pdf.

[10] PCAST, note 1, supra, and Notice of Proposed Rulemaking and Order, In the Matter of Amendment of the Commission's Rules with Regard to Commercial Operations in the 3550-3650 MHz Band, Before the Federal Communications Commission, GN Docket No. 12-354, released December 12, 2012 ("FCC 3.5GHz NPRM"), available at: http://apps.fcc.gov/ecfs/document/view?id=7022080889.

[11] Third Report & Order, In the Matter of Unlicensed Operation in the TV Broadcast Bands (ET Docket No. 04-186), Additional Spectrum for Unlicensed Devices Below 900 MHz and in the 3 GHz Band (ET Docket No. 02-380), Before the Federal Communications Commission, Released April 12, 2012 ("FCC TVWS 3rd R&O (April2012)"), available at: http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-12-36A1.pdf.

[12] Notice of Proposed Rulemaking, In the Matter of Revision of Part 15 of the Commission's Rules to Permit Unlicensed National Information Infrastructure (U-NII) Devices in the 5 GHz Band, Before the Federal Communications Commission, ET Docket No. 13-49, released February 20, 2013 ("FCC 5GHz NPRM"), available at: http://transition.fcc.gov/Daily_Releases/Daily_Business/2013/db0220/FCC-13-22A1.pdf

[13] IEEE P1900.1 Draft Standard

[14] See http://www.qualcomm.com/solutions/wireless-networks/technologies/1000x-data.

[15] First Report and Order, In the matter of Revision of Part 15 of the Commission's Rules Regarding Ultra-Wideband Transmission Systems, Before the Federal Communications

Commission, Released April 22, 2002, available at: http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-02-48A1.pdf ("FCC UWB Order (April2002)").

[16] For example, on January 14, 2014, the FCC hosted a 3.5GHz Spectrum Access System Workshop to explore approaches to these issues (see, http://spectrumworkshop.uservoice.com/).

[17] See http://ec.europa.eu/digital-agenda/en/rspp-roadmap-wireless-europe.

[18] The RSPG is an advisory group to the European Commission comprised of member-state representatives with expertise on wireless and spectrum-related matters. See http://ec.europa.eu/digital-agenda/en/radio-spectrum-policy-group-rspg.

[19] RSPG Request for Opinion on Licensed Shared Access (LSA) – Document RSPG12-424 Rev2, 8 November 2012 http://rspg.groups.eu.int/_documents/documents/meeting/rspg29/rspg12-424_final-rfo_lsa.pdf

[20] Draft RSPG Opinion on Licensed Shared Access – Document RSPG13-529 rev1, 30 May 2013 https://circabc.europa.eu/sd/d/dc44e39f-7fab-4cc2-8513-f6fce5c25c34/RSPG13-529rev1-Draft%20RSPG%20Opinion%20on%20LSA.pdf

[21] European Conference of Postal and Telecommunications Administrations – 48 European countries cooperating to regulate radio spectrum and communications networks. www.cept.org.

[22] CEN is the European Committee for Standardization, CENELEC is the European Committee for Electrical Standardization, and ETSI is the European Telecommunications Standards Institute (see, http://www.cencenelec.eu/Pages/default.aspx).

[23] See http://ec.europa.eu/enterprise/standards_policy/mandates/database/index.cfm?fuseaction=search.detail&id=515.

[24] See http://www.itu.int/newsroom/wrc/2007/itur_web_flash/20071019.html.

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

[26] CEPT FM Project Team 53 on Reconfigurable Radio Systems (RRS) and Licensed Shared Access (LSA) Terms of Reference http://www.cept.org/ecc/groups/ecc/wg-fm/fm-53/page/terms-of-reference

[27] See http://www.etsi.org/news-events/news/410-reconfigurable-radio-systems-workshop-12-december-2012-sophia-antipolis-france.

[28] GSMA Public Policy Position on Licensed Shared Access (LSA) and Authorized Shared Access (ASA) http://www.gsma.com/spectrum/licensed-shared-access-lsa-and-authorised-shared-access-asa

[29] DIGITALEUROPE response to draft RSPG Opinion on Licensed Shared Access (LSA) http://www.digitaleurope.org/DocumentDownload.aspx?Command=Core_Download&EntryId=593

[30] See http://www.vtt.fi/news/2013/25042013_ASA.jsp?lang=en.

[31] See Notice of Proposed Rulemaking and Order, In the Matter of Amendment of the Commission's Rules with Regard to Commercial Operations in the 3550-3650 MHz Band, Before the Federal Communications Commission, GN Docket No. 12-354, released December 12, 2012 ("FCC 3.5GHz Small Cells NPRM"), available at: http://apps.fcc.gov/ecfs/document/view?id=7022080889.

[32] See *3.5 GHz Small Cells NPRM* at ¶ 6 (identifying 3.5 GHz as the "ideal band in which to propose small cell deployments and shared spectrum use"; noting that the incumbent uses in the band include high powered Department of Defense radars, non-federal Fixed Satellite Service ("FSS") earth stations for receive-only, space-to-earth operations and feeder links, and that the adjacent band below 3550 MHz contains high-powered ground and airborne military radars).

[33] See PCAST (2012), "Report to the President: Realizing the Full Potential of Government-Held Spectrum to Spur Economic Growth," President's Council of Advisors on Science and Technology (PCAST), July 2012, available at: http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast_spectrum_report_final_july_20_2012.pdf.

[34] See Commission seeks comment on Licensing Models and Technical Requirements in the 3550-3650 MHz Band, Before the Federal Communications Commission, GN Docket No. 12-354, released November 1, 2013 ("FCC 3.5GHz Licensing Framework PN"), available at: http://transition.fcc.gov/Daily_Releases/Daily_Business/2013/db1104/FCC-13-144A1.pdf.

[35] The workshop, originally scheduled for December 2013 was rescheduled for January 14, 2014, see http://www.fcc.gov/events/35-ghz-spectrum-access-system-workshop.

[36] March 20th, 2013 Letter from FCC Chairman to NTIA Administrator Releases

National Telecommunications & Information Administration (NTIA)
"An Assessment of the Viability of Accommodating Wireless Broadband in the 1755-1850 MHz Band", U.S. Department of Commerce, March 2012, available at: http://www.ntia.doc.gov/report/2012/assessment-viability-accommodating-wireless-broadband-1755-1850-mhz-band.

[39] Congress has mandated that the FCC allocate and license the 2155-2180 MHz spectrum by February 2015.

[40] 3GPP Band 10

[41] [Ref 4.23] CCP.II-RADIO/doc. 3295/13 Draft Recommendation on "Use of 1710-1780 / 2110-2180 MHz BANDS IN THE AMERICAS FOR BROADBAND MOBILE SERVICES", 11 April 2013, http://www.oas.org/es/citel/P2!R.htm

[42] U.S. Commerce Spectrum Management Advisory Committee (CSMAC) http://www.ntia.doc.gov/category/csmac

[43] CSMAC WG 5 Final Report, "1755-1850 MHz Airborne Operations (Air Combat Training System, Small Unmanned Aircraft Systems, Precision Guided Munitions, Aeronautical Mobile Telemetry)," Final Report of Working Group 5 (Sept. 16, 2013) available at http://www.ntia.doc.gov/files/ntia/publications/wg5_1755-1850_final_reportl-09-16-2013.pdf.

[44] Wireless Industry letter to NTIA on 1755-1780 MHz Band http://files.ctia.org/pdf/filings/CTIA_files_letter_with_NTIA_on_1755-1780_MHz_Band.pdf

[45] See Notice of Proposed Rule Making, In the Matter of Unlicensed Operation in the TV Broadcast Bands (ET Docket No. 04-186), Additional Spectrum for Unlicensed Devices Below 900 MHz and in the 3 GHz Band (ET Docket No. 02-380), Before the Federal Communications Commission, Released May 25, 2004, available at: http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-04-113A1.pdf ("FCC TVWS NPRM (May2004)").

[46] Third Report & Order, In the Matter of Unlicensed Operation in the TV Broadcast Bands (ET Docket No. 04-186), Additional Spectrum for Unlicensed Devices Below 900 MHz and in the 3 GHz Band (ET Docket No. 02-380), Before the Federal Communications Commission, Released April 12, 2012, available at: http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-12-36A1.pdf ("FCC TVWS 3rd R&O (April2012)")

[47] See Notice of Proposed Rulemaking, In the Matter of Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions, Before the Federal Communications Commission, Docket No. 12-268, released October 2, 2012 ("FCC Incentive Auction NPRM"), available at: http://www.fcc.gov/document/broadcast-television-spectrum-incentive-auction-nprm.

[48] See http://variety.com/2014/tv/news/fcc-chairman-tom-wheeler-pitches-broadcasters-on-once-in-a-lifetime-chance-to-auction-spectrum-1201040801/.

[49] See Notice of Proposed Rulemaking, In the Matter of Revision of Part 15 of the Commission's Rules to Permit Unlicensed National Information Infrastructure (U-NII) Devices in the 5 GHz Band, Before the Federal Communications Commission, ET Docket No. 13-49, released February 20, 2013 ("FCC 5GHz NPRM"), available at: http://transition.fcc.gov/Daily_Releases/Daily_Business/2013/db0220/FCC-13-22A1.pdf.

[50] The regulator may be the National Regulatory Agency (NRA) or a Non Governmental Organization (NGO), for example, a third-party band manager.

[51] See, for example, "Mobile Broadband: the Benefits of Additional Spectrum," Federal Communications Commission (FCC) Staff Technical Paper, October 2010, available at: http://download.broadband.gov/plan/fcc-staff-technical-paper-mobile-broadband-benefits-of-additional-spectrum.pdf; 4G Americas (2011), "Sustaining the Mobile Miracle: A 4G Americas Blueprint for Securing Mobile Broadband Spectrum in this Decade," March 2011, available at: http://www.4gamericas.org/UserFiles/file/White%20Papers/4G%20Americas%20Mobile%20Broadband%20Spectrum%20Requirements%20March%202011.pdf;or, ITU (2006), "Estimated Spectrum Bandwidth Requirements for the Future Development of IMT-2000 and IMT-Advanced, Report ITU-R M.2078, International Telecommunications Union (2006), available at: http://www.itu.int/dms_pub/itu-r/opb/rep/R-REP-M.2078-2006-PDF-E.pdf.

[52] The exclusive-use licensee is still bound by the terms of the government assigned license which may specify technology, build-out, usage, terms, or other duties and obligations. However, increasingly, mobile licenses allow operators to design their services (service neutrality) and may afford significant latitude in the choice of technology (technology neutrality) and do not impose an obligation to sub-lease and allow the licensee great flexibility in establishing the terms for allowable leases. This single-agent control is why we refer to this as "cooperative" sharing.

[53] Secondary users may but are not obligated to coordinate in their use of the spectrum. This can result in a Tragedy of the Commons among unlicensed users if too many users seek to use the spectrum simultaneously. Additionally, in the case of underlay/overlay easements in primary-licensed spectrum, secondary users do not need to seek permission from the primary licensee to operate and so the sharing between primary and secondary users is also non-cooperative.

[54] RSPG (2011), "Report on Collective Use of Spectrum (CUS) and other spectrum sharing approaches," Radio Spectrum Policy Group (RSPG11-392 Final), November 2011, available at: http://rspg-spectrum.eu/_documents/documents/meeting/rspg26/rspg11_392_report_CUS_other_approaches_final.pdf.

[55] Parcu, P., A. Nicita, G. Corda, M. Rossi, and L. Bravo (2011), "Authorised Shared Access (ASA): An Innovative Model of Pro-Competitive Spectrum Management," May 1, 2011, available at SSRN: http://ssrn.com/abstract=2174518.

[56] See page 2, GSMA (2013), "Licensed Shared Access (LSA) and Authorised Shared Access (ASA)," February 2013, available at: http://www.gsma.com/spectrum/wp-content/uploads/2013/04/GSMA-Policy-Position-on-LSA-ASA.pdf.

[57] See "Mobile Broadband: the Benefits of Additional Spectrum," Federal Communications Commission (FCC) Staff Technical Paper, October 2010, available at: http://download.broadband.gov/plan/fcc-staff-technical-paper-mobile-broadband-benefits-of-additional-spectrum.pdf.

[58] See Sharma, C. (2013), "Mobile 4th Wave: Evolution of the Next Trillion Dollars," Mobile Future Forward, Seattle, September 2013, available at: http://www.chetansharma.com/Fourth_Wave_Evolution_of_the_Next_Trillion_Dollars_Chetan_Sharma_Consulting.pdf.

[59] See Deloitte (2014), "The Impact of Licensed Shared Use of Spectrum," a white paper prepared for GSMA, in conjunction with RealWireless, 23 January 2014, available at: http://www.gsma.com/spectrum/wp-content/uploads/2014/02/The-Impacts-of-Licensed-Shared-Use-of-Spectrum.-Deloitte.-Feb-20142.pdf.

[60] See Katz, Raul (2014), "Assessment of the Economic Value of Unlicensed Spectrum in the United States," Telecom Advisory Services, LLC, February 2014, available at: http://www.wififorward.org/wp-content/uploads/2014/01/Value-of-Unlicensed-Spectrum-to-the-US-Economy-Full-Report.pdf. This study was commissioned by WiFiForward, a consortium including Google and Comcast, among others.