COMMERCE SPECTRUM MANAGEMENT ADVISORY COMMITTEE (CSMAC)

Report of Subcommittee on CBRS

Co-Chairs: Jennifer McCarthy, Mariam Sorond, Patrick Welsh

Jennifer Alvarez
Reza Arefi
Donna Beathea-Murphy
Michael Calabrese
Thomas Dombrowsky
Mark Gibson
Carolyn Kahn
Karl Nebbia
Paul Margie
Louis Peraertz
Dennis Roberson
Steve Sharkey
Rikin Thakker
Bryan Tramont
Jennifer Warren
David Wright

NTIA Liaisons: Nick LaSorte and Ed Drocella
FCC Liaisons: Kevin Holmes and Jessica Quinley

REPORT

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1. Introduction

The National Telecommunications and Information Administration (NTIA) provided the following background and questions to the Commerce Spectrum Management Advisory (CSMAC) Subcommittee on the Citizens Broadband Radio Service (CBRS):

Background: "There has been increasing spectrum sharing between federal and non-federal users. In 2020, federal and non-federal users started dynamically sharing the 3550-3650 MHz portion of the Citizens Broadband Radio Service (CBRS) band. The foundation of CBRS is a novel sharing framework that includes a three-tiered licensing scheme that grants corresponding levels of protections from other users, including fully protecting incumbent operations including those of federal entities, and employs multiple Spectrum Access Systems (SAS) and an environmental sensing capability (ESC) network. After initially enabling General Authorized Access (GAA), the FCC's auction of Priority Access Licenses (PALs) for the CBRS band concluded approximately two years ago and it completed granting licenses one year ago, on December 9, 2021.[1] NTIA would like to learn what, at this stage, is working well and what may not be with this leading example of federal government/commercial sharing; what, if anything, could/should be improved for CBRS; and to what extent CBRS can and should inform our efforts to explore and advance spectrum sharing in other bands."

[1] The FCC's PAL auction concluded in September 2020, with licenses issued starting March 2021 to October 2022.

NTIA Questions to CSMAC:

1. What are general and specific lessons learned from the CBRS framework for commercial operations sharing with federal incumbents - both positive and negative?
2. How could the commercial-federal sharing in CBRS be improved?
3. What from this CBRS spectrum sharing experience should be considered for implementation in other bands/cases?
4. What from this CBRS spectrum sharing experience should be avoided in other bands/cases?

CBRS Subcommittee Questions to Stakeholders:

The Subcommittee started work in January 2023 by first providing more details to the questions provided by NTIA as outlined below and then scheduling interviews with CBRS stakeholders to collect background so that it could provide recommendations to NTIA.

1. Please provide a background on your company and your involvement in CBRS, which category would you consider yourself in: PAL licensee, GAA licensee, equipment provider, SAS provider, federal incumbent, federal/regulatory agency, trade association, academia, technical/lab, other?

2. What are general and specific lessons learned from the CBRS framework for commercial operations sharing with federal incumbents - both positive and negative?
    a. What are the technical lessons learned? What changes have you implemented based on what you learned?
    b. What are the policy/regulatory lessons learned? What changes have you implemented based on what you learned?
    c. What are the operational lessons learned? What changes have you implemented based on what you learned?
    d. What are the process lessons learned? What changes have you implemented based on what you learned?
    e. What are the economic lessons learned? What changes have you implemented based on what you learned?
    f. What are the standards/certification development process lessons learned?
    g. What are the lessons learned from a three-tier sharing framework?
    h. What are the lessons learned from an ESC or more broadly a sensing framework for sharing? How scalable is a sensing framework?
    i. What are the lessons learned from using a scheduling/informing portal? How scalable is a scheduling/informing portal?
    j. Can you quantify/describe the impact in terms of cost, timeline, risk of those lessons learned both positive/negative?

3. How could the commercial-federal sharing in CBRS be improved?
    a. How could this be improved under the current approach and please propose another approach that you think would work better for things that may be able to be enhanced such as propagation modeling, timing on activation of Dynamic Protection Areas (DPAs), etc. within CBRS?
    b. How could the timing and availability of information be improved for informed decision-making?

4. What from this CBRS non-federal and federal spectrum sharing experience should be considered for implementation in other bands/cases?
    a. Please specify the non-federal use case and band that you are proposing for such an implementation for a non-federal and federal sharing case.
    b. In any future ship/air/ground borne federal and non-federal sharing, should we use the mechanisms from CBRS, or should we use different ones?
    c. What could be leveraged from the lessons learned from above using sensors/portals to inform on federal incumbent spectrum for future federal and non-federal sharing?

5. What from this CBRS non-federal and federal spectrum sharing experience should be avoided in other bands/cases?
    a. In any future ship/air/ground borne federal and non-federal sharing, should we avoid any of the mechanisms in CBRS?
    b. What lessons learned from using sensors/portals to inform on federal incumbent spectrum use should be avoided for future federal and non-federal sharing?

The subcommittee held monthly meetings, interviewing multiple stakeholders as outlined in Section 2. Subsequently the responses were categorized and presented in Section 3, covering technical and sensing, policy and economic, operational and process, and standards and certification aspects of the CBRS band. Additionally, feedback was collected with respect to using the CBRS framework in other spectrum bands, the results of that are presented in section 4. Finally, based on the responses, recommendations that are presented in section 5 are proposed to the NTIA.

2. Stakeholders Represented

The CBRS band allows for flexible deployments across multiple use cases. Among the commercial users, there are different stakeholders that include operators, equipment providers, and private enterprises, including research and academic institutions. There are also multiple associations and standards development organizations (SDOs) that define specifications and operational parameters for the band. The Subcommittee interviews were intended to gather as many different perspectives from across a wide range of stakeholders as possible and the table below categorizes the entities interviewed.

The Subcommittee conducted 33 interviews with the following stakeholders:

Government Stakeholders (Operators, Regulators and Labs)	• U.S. Department of Defense (DoD), Office of the CIO • U.S. Department of the Navy • National Advanced Spectrum and Communications Test Network (NASCTN) • NTIA • Institute for Telecommunication Sciences (ITS)
CBRS Operators and Their Trade Associations	• AT&T • Cal.net • CalPoly • Charter • City of Las Vegas

	• Comcast • CTIA • DISH • Kyndryl • NCTA • T-Mobile • Verizon • WISPA
SAS Providers	• CommScope • Federated Wireless • Google • Red • Sony
SDOs and Industry Associations	• CableLabs • OnGo Alliance • WInnForum
Equipment Providers	• Airspan • Celona • Ericsson • Nokia • Qualcomm
Academics, Researchers, and Individual Contributors	• SpectrumX • Former FCC Official

3. Stakeholder Lessons Learned and Views on Improvements

3.1. Technical and Sensing

Government Stakeholders. Government commenters indicated that there have been no reports of interference by federal incumbents since commercial CBRS operations started in 2019. Government stakeholders noted that the federal incumbent protection requirements initially established for CBRS operations were intentionally conservative and that it was anticipated that changes to these requirements could be made over time once real-world experience was gained. Government stakeholders also noted that changes that are being considered by the federal government include: (1) updating the propagation model, including allowing the use of clutter data; (2) reducing the amount of time DPAs must remain active after a radar signal is no longer detected; and (3) reducing the heartbeat interval for CBRS devices (CBSDs) outside of DPA neighborhoods. One government operator noted that while the use of sensors to enable sharing between federal and non-federal users has proven to be successful, their use has not been without challenges. ESC sensor reliability and failures as well as limitations on what an ESC sensor can detect were identified as two such challenges.

CBRS Operators and Their Trade Associations. Fixed wireless providers and new-entrant wireless companies, along with their corresponding associations, private wireless network operators, and one nationwide mobile network operator, generally stated the CBRS sharing framework has proven to be successful from a technical perspective. One commenter noted that a multi-tier, web-enabled sharing framework is feasible, the DPA approach is better than exclusion zones originally adopted by the FCC to protect federal incumbents, the SAS interference calculations work, the ESC sensors work, DPA portals work, and PAL protection areas work. Multiple private wireless network operators indicated that their operations were not impacted by federal incumbent use of the band.

Several operators stated that the complexity of the CBRS sharing framework results in costs and adverse impacts on operations. One common observation was that the reliance on ESC sensors has had an unintended consequence, namely the Whisper Zones that are necessary to protect ESC sensors reduce commercial spectrum availability along the coasts. Other common observations included: (1) inclusion of clutter data in interference protection calculations will reduce the DPA neighborhood size and greatly increase spectrum availability for commercial users without adversely impacting federal incumbents; (2) relaxation of highly conservative federal incumbent protection reliability will make more spectrum available for commercial use without jeopardizing federal incumbent operations; (3) the requirement for aggregate interference protection adds significant complexities to SAS operations and prevents real-time channel assignments and changes due to the overnight SAS coordination process; (4) ESC sensors are costly to deploy and maintain; and (5) other federal protection requirements are unnecessarily conservative. For instance, several commenters noted that the amount of time that DPAs must remain active after radar use is no longer detected should be reduced and that the heartbeat interval for CBSDs outside of DPA neighborhoods should also be reduced.

Nationwide mobile network operators and their industry association, including a new-entrant operator, indicated that the CBRS transmit power levels and out-of-band emissions (OOBE) limits are overly restrictive, which negatively impacts the ability of these operators to design and deploy wide-area mobile networks in an efficient and cost-effective manner. Two new-entrant MVNO operator and their industry association and some private wireless network operators, on the other hand, did not see a need for higher transmit power limits for their use cases and noted that allowing higher transmit power would increase the risk for interference amongst CBRS users, especially in the GAA tier. They also expressed concern that the risk of interference would be exacerbated without a requirement for Time Division Duplex (TDD) synchronization amongst CBRS users. One nationwide operator stated increasing CBSD power limits would disenfranchise GAA users to the benefit of PALs and stated the interference margin to protecting Federal users would decrease, resulting in the GAA tier being denied access where it otherwise would not. One commenter suggested that increased transmit power limits could be implemented in rural and non-DPA areas to avoid interference amongst CBRS users and to federal incumbents.

Several operators stated that a lack of clear FCC requirements for co-existence within the GAA tier and the resulting inability for the SAS administrators to enforce co-existence has resulted in interference amongst GAA users.

SAS Providers. The SAS providers described the current federal incumbent protection requirements as being overly conservative. Providers recommended changes that should be implemented, including: (1) updating the propagation models used and including clutter data in interference protection calculations; (2) reducing the DPA activation timer; (3) reducing the CBSD heartbeat interval outside of DPA neighborhoods; and (4) reducing the complexity of aggregate interference protection so that spectrum grants can be made closer to real time rather than having to

wait for the overnight SAS coordination process. It was noted that the overnight SAS coordination process results in impacted commercial users to remain in a suspended state during DPA activations due to a lack of dynamic channel re-assignment capability.

With regard to sensing, one provider noted that the ESC sensors are working well and were the reason that sharing between federal and non-federal users in CBRS was implemented quickly and efficiently. Two providers stated that the Whisper Zones around each ESC sensor cause CBSDs to be shut down or operated at a much lower power levels – a problem that is compounded by having multiple ESC providers.

SDOs and Industry Associations. The commenters indicated that the three-tiered shared framework, managed by a centralized, dynamic system, works, and has resulted in protection of federal incumbents, which have not reported any interference from commercial operations. However, the commenters noted that improvements to the framework are necessary to increase efficient use. For instance, the commenters recommended that newer, less conservative propagation models should be used. Commenters also indicated that the need for Whisper Zones around the ESC sensors was an unanticipated problem that should be revisited to minimize the impact on spectrum availability for commercial operations along the coasts.

Equipment Providers. The equipment providers indicated that dynamic sharing works from a technical perspective, however the CBRS framework is complex and imposes costs on operators and equipment vendors. Commenters also noted that there are problems associated with losing access to spectrum when SAS connectivity is compromised, that incumbent operations are likely over-protected, and the presence of multiple sensing networks causes inefficient use of spectrum due to Whisper Zone protection requirements. Commenters indicated that the propagation model used for incumbent protection is overly conservative, the heartbeat interval for CBSDs outside of DPA areas should be re-visited, and the complex aggregate interference coordination mechanisms delay spectrum allocations for up to 24 hours, which causes significant impact on network operators. One commenter noted that the aggregate interference coordination requirement also eliminates innovation that could result from an ecosystem of numerous competing SASs. One commenter indicated that co-existence amongst GAA operators has been problematic given that the SAS administrators have not implemented protocols to prevent one user from requesting channel assignments that would interfere with another user.

Academics and Researchers. One research organization indicated that it has conducted experiments to quantify the effect of adjacent-channel interference between CBRS and C-band due to mismatches in uplink/downlink TDD configurations. It demonstrated an almost 60% reduction in downlink throughput on CBRS when a C-band device in the vicinity is transmitting uplink and a smaller reduction of 43% in C-band throughput. The researcher noted that a similar adjacent-channel interference problem will arise once 5G is deployed in the 3.45-3.55 GHz band. Another study being conducted is of a CBRS deployment where it has been observed that neighboring CBSDs deployed on the same channel cause reduction in throughput, which likely lead to the need for more shared spectrum as deployments increase.

3.2. Policy and Economic

Policy Observations and Lessons Learned

Government Stakeholders. Government commenters generally indicated that the three-tiered sharing framework has so far proven to be a positive spectrum access solution for protecting federal users and enabling them to continue to meet their missions while opening up unique and innovative commercial sharing opportunities. However, government stakeholders underscored that clear, concise communication among stakeholders is necessary and that funding requests need to be adjusted to support the number of meetings and ongoing work. For instance, a government operator stated the CBRS framework is not being employed by some CBRS users as advertised, as CBRS users have sought resolution outside the dictates of the FCC process. Additionally, the government operator indicated industry partners may need assistance to understand how the government uses spectrum to improve mitigation techniques, coordination, and network planning processes. The government operator also suggested that the FCC implement an awareness campaign with actual users and system implementers during its proceedings and expressed a desire to continue to have good working relationships with CBRS industry partners. Another government operator stated there may be opportunities to look at global spectrum sharing issues. A government lab commenter indicated that additional hardware and signal processing changes are needed to better characterize the upper 50 megahertz of the CBRS band.

CBRS Operators and Their Trade Associations. Fixed wireless providers, new-entrant wireless companies, and their corresponding associations, generally stated that the CBRS framework has served to protect incumbents, diversify use of the band, enhance opportunities for private networks, promote efficient spectrum use, and lay a foundation for dynamic spectrum sharing possibilities, including through the licensing and technical rules that were adopted for PAL and GAA operations. For instance, an industry association stated that the number of auction and GAA participants demonstrates the diversity of users that rely on spectrum for their business and communication needs and that that there is an appetite for low-barrier access to spectrum. A new-entrant wireless provider stated the CBRS framework has encouraged competition and rapid network deployment. A vendor for smaller private wireless operators also indicated that they had more flexibility in meeting customers unique security and other network control requirements through the CBRS framework given that a private wireless network can be directly integrated into enterprise networks. These commenters generally supported the license sizes and power limits adopted for the band.

Nationwide wireless companies and a trade association stated the complexity of the band and the licensing and technical rules adopted have unintentionally inhibited network coverage and created unpredictable service quality in the band. Nationwide wireless providers stated these uncertainties, including the band's power levels, have resulted in CBRS functioning only as a supplementary band that complements traditional licensed spectrum. Another nationwide provider also stated clearing spectrum, when possible, is preferred for the most efficient and effective use and that sharing structures should be kept as simple as possible and only when clearing is not feasible. The same provider stated that an operator that depends on GAA to have enough total spectrum to justify deployment risks having other providers subsequently using the same band in other tiers. This risk of subsequent interference risk undermines the viability of deployment based on spectrum access and may render that spectrum effectively useless. An association stated that the CBRS band has not produced the innovation that was hoped and has a lower value compared to other mid-band frequencies based on auction results. A nationwide wireless provider stated the PAL buildout obligations are impractical and disincentivize secondary market transactions.

Industry commenters agreed that the CBRS framework has served to protect incumbent federal operations, with one association suggesting the incumbent protections are overly conservative and limit full utility of the band and another indicating the lack of interference demonstrates the framework was

successfully implemented. Industry commenters made several other policy points regarding the framework, including: (1) the Certified Professional Installer (CPI) requirements can lead to bottlenecks (fixed wireless provider); (2) additional FCC guidelines to require GAA co-existence and to encourage more dynamic sharing would be helpful (new-entrant wireless provider and two nationwide wireless providers); (3) further work should be done to ensure commercial operators have flexibility in choosing a SAS provider (new-entrant wireless provider); (4) measuring and reporting actual usage would allow for prioritization of more intensive use (fixed wireless provider); and (5) the FCC's processes for software upgrades for CBRS equipment testing should be improved (nationwide wireless provider).

SAS Providers. Several SAS providers stated the CBRS framework has shown a three-tier model is feasible and desirable, but noted the technical complexity of SAS design and implementation which may benefit from changes to the framework. One provider called for the development of a self-certification framework that does not require re-testing by ITS. This SAS provider also stated a framework is needed to allow for participation from all stakeholders in discussions with regulators and DoD (not just with SAS and ESC providers). Another stated consideration should be given as to whether PAL operations should have regulatory priority over GAA operations when incumbent protection is implemented and that an automated PAL channel reassignment process is needed when DPA activations impact PAL operations. The provider also indicated that fragmented power limits across the 3 GHz band have impacted 5G equipment development, stating power level and OOBE limit parity across the 3.45 GHz band, CBRS, C-band, and 3.1-3.45 GHz band would be beneficial. One provider stated the goal should be to ensure stable operations, particularly for GAA operators. One provider stated that the term "sharing" needs to be clarified, as DoD's ability to retake spectrum with little or no notice does not constitute sharing. The same provider called for a streamlined process for modifying the rules for the band as needed, as rulemakings and standards are too slow.

SDOs and Industry Associations. One organization discussed the technical complexity of the three-tier framework but stated the model works and can be utilized in future bands as appropriate. Another highlighted the success of the framework came from collaboration at the highest levels and discussed the need to preserve and in some cases establish collaborative relationships with FCC, NTIA, DoD, and industry. This organization noted that targeted and scheduled meetings to prioritize improvements to the framework are needed to assess adjustments based on real-world observations.

Equipment Providers. One equipment vendor stated the CBRS regulatory framework (as opposed to full-power, licensed spectrum) ignores the wide area propagation characteristic across the 3 GHz band by restricting the allowed power levels and imposes U.S.-specific 5G NR (new radio) radios on the market, undermining U.S. technology leadership. Another stated that large protection distances can have significant commercial impact. Another equipment provider stated negotiations between new entrants and incumbents on spectrum sharing rules within larger multistakeholder groups is not workable where there are no incentives for incumbents to make concessions. This equipment provider further stated that rulemakings could be made more effective by defining the outcomes while leaving the technical details, testing, and certification to industry to resolve through standardization processes, industry bodies, and commercial test labs.

Academics and Researchers. An academic noted an ongoing study that is producing an empirical comparison between CBRS and AMBIT (Americas Mid-Band Initiative Teams) used to allocate radio spectrum in the 3.5 GHz band. Another noted the potential to leverage edge-based sharing techniques to get more intensive GAA use.

Economic Observations and Lessons Learned

Multiple operators indicated that the use cases deployed in the CBRS band provide economic benefits compared to other licensed or unlicensed spectrum. A new-entrant wireless company indicated the availability of several SAS providers keeps monthly recurring costs reasonable at scale and a fixed wireless provider stated the SAS model is economically supportable. On the other hand, a fixed wireless provider stated the CBRS framework has increased the cost of doing business in the former 3.65 GHz Part 90 band and a nationwide wireless provider stated operational costs of accessing the SAS and unstable SAS connectivity has impacted the viability of business models relying on the band. A nationwide wireless provider stated the three-tier sharing framework makes the availability of interference-free spectrum unpredictable in a given location, making it hard to justify investment. The same provider stated power and propagation limitations make it cost-prohibitive to deploy in the band at any meaningful scale for wide-area coverage, resulting in use of the band for small private networks or small-cell augmentation. An equipment vendor stated it does not have any cost concerns so long as there is sufficient interest from its customers to use CBRS. A nationwide wireless provider stated the CBRS NH MOCN (Neutral Host Multi-Operator Core Networks) architecture offers a cost-effective network deployment solution.

Two SAS providers raised concerns regarding whether CBRS has a viable long-term economic path for SAS administrators, noting the costs of a centralized, cloud-based sharing system compared to the revenue generated. One of these SAS providers stated the government must help make sharing successful by working to remove or improve impediments, and the other stated the ESC is an unnecessary cost and can be replaced by a portal such as the Telecom Advanced Research and Dynamic spectrum sharing system (TARDYs3) to give longer economic viability to SAS administrators. Another SAS provider stated the economic model for multiple third-party commercial SASs and ESCs is challenging, and the concept of dynamic sharing is not yet broadly acceptable, thus CBRS users have been resistant to the inherent costs of shared-spectrum access. An industry association stated that funding future federal participation (DoD, NTIA, FCC) in the Wireless Innovation Forum (WInnForum) is needed if future bands are to be studied for sharing.

3.3. Operational and Process

Operational Observations and Lessons Learned

Government Stakeholders. A government operator stated that industry has asked for more predictability, which leans toward a scheduling tool such as the Incumbent Informing Capability (IIC), even as DoD is thinking ahead to more dynamic sharing through automation. A government regulator stated it has been challenging to understand CBRS commercial deployment models and to incorporate the multiple types of such models into their analysis. A government lab discussed sensor architectures, stating they will be modified from their prototype implementation through a refinement in preselector filtering and signal processing to account for the presence of 3GPP deployments in the 3.7-3.98 GHz band and to include 3.45-3.55 GHz band.

CBRS Operators and Their Trade Associations. A nationwide wireless association stated the CBRS requirement to retune and avoid DoD operations reduces the amount of usable spectrum for CBRS operations. An association and three providers stated CBRS is limited to a complementary role to nationwide deployments. On the other hand, a fixed wireless association and fixed wireless provider noted CBRS can be deployed for both LTE and non-LTE private networks and for 5G coverage in campus settings. A fixed wireless company indicated it has not seen DoD activations in its customers' facilities and

has deliberately told customers not to put mission-critical traffic on CBRS spectrum. Another fixed wireless entity called for field installers to gather correct Height Above Average Terrain level and GPS or location coordinates of client CBSDs so SAS entries are correct. It also recommended eliminating the need for CPIs to install high-power customer premises equipment. A new entrant wireless provider stated failure to protect CBRS from C-band and 3.45 GHz operations will create interference effects, necessitating TDD synchronization between these bands with potentially more stringent FCC requirements. A nationwide wireless provider discussed how DoD unexpectedly began operating on all of the PAL channels at inland bases. The provider stated that, in such a case, there is no recourse for PAL licensees, which leads to GAA channels being more desirable, as there is nothing in the rules that says PAL usage should be prioritized when PAL channels are occupied by DoD. The provider also stated higher power limits could be useful in rural areas, in areas away from the coasts, and for PAL operations. A new entrant wireless association stated PAL owners are not far enough along in deployment to think about leasing CBRS spectrum and stated there is no need for higher power when using stand-mounted small cells and where there could be negative impacts on GAA operations. A nationwide wireless provider stated it is almost impossible to get stable spectrum allocations in areas of need (e.g., coastal high population centers) since incumbent federal users frequently limit access. Another nationwide provider similarly stated additional operational complexity stems from the dynamic nature of the frequency assignments, making spectrum planning and network management complicated due to potential radio channel assignment changes. One operator also noted the challenges associated with the uncertainty of the changes to the FCC authorization with respect to CBRS devices as the FCC has been updating its authorization procedure due to national security concerns.[2]

SAS Providers. One SAS provider discussed that, in some areas of the country, the commercial CBRS services have been significantly interrupted due to federal operations, making it challenging for certain users and business models. It recommended that the FCC educate prospective CBRS users about the realities of the dynamic shared framework and the impact on commercial use of the band to better manage expectations. The provider also noted that technical solutions are required to maintain commercial operation in the event CBSD connectivity to a SAS is interrupted, noting as an example that there are proprietary solutions in development that could address this problem, as would the extension of transmit expiry times (especially outside DPA neighborhoods). One provider stated centralized dynamic sharing works, another provider stated keeping SAS administrator costs bearable is the main challenge, and another highlighted operational concerns with continuous 24/7 SAS operation using the public cloud environments. Another SAS provider stated daily SAS overnight coordination (CPAS) prohibits the ability to dynamically manage spectrum, as the SAS cannot easily move CBSDs to another channel due to DPA activation since it has to wait for CPAS to run. The provider also stated the lack of reports of interference shows DoD operations are being overprotected, and the interference protection criteria should be revisited and based on real interference, not interference potential.

SDOs and Industry Associations. One provider highlighted that the unexpected need for ESC sensors to be protected has led to inefficiencies in spectrum usage given the large Whisper Zones around multiple ESC sites. Another highlighted that there were good discussions and relationships at the staff level between FCC, NTIA, and DoD that helped make CBRS happen, including an engineering group that met regularly to work through issues without putting burdens solely on DoD (e.g., addressing preliminary operations-security concerns through the use of ESCs). Another SAS provider indicated: (1) centralized dynamic spectrum sharing works with certain use cases, but enhancements are necessary to increase the

[2] Secure and Trusted Communications Networks Reimbursement Program.

efficient use of the shared spectrum; (2) sharing rules should accommodate innovative new propagation models, as well as improvements; (3) there are implementation complexities associated with aggregate interference; (4) incumbent activity detection using dedicated sensors is problematic; (5) coexistence among peer users should be a fundamental consideration in future sharing frameworks; (6) enforcement is a government function; (7) the FCC should help educate users on the limitations and expectations of the band; (8) the goal for dynamic resource allocation timescales should be near real time; (9) certification of virtualized/disaggregated radio technology should be accommodated (10) the FCC should advocate for technical solutions in shared spectrum, with other government agencies, in support of industry; (11) the FCC needs to provide better foresight and coordination of adjacent band situations; and (12) the FCC's Universal Licensing System (ULS) is not optimized for many spectrum sharing applications because it is incomplete, inaccurate, and/or lacks required information to perform more accurate interference analyses.

Equipment Providers. One vendor noted that, due to suspensions, customers who are running mission-critical applications using CBRS cannot use the lower 100 megahertz of CBRS spectrum, and there might be higher contention or interference in the remaining 50 megahertz. This vendor stated its approach is to be a good neighbor in the band so as not to reduce the power budget in a specific locality for all users. Another equipment provider stated PAL licensees should be accorded priority, which is not reflected in the way the SAS manages interference budgets associated with incumbent operations when coordinating spectrum use, and discussed uncertainty with the framework that results in less optimized use of the band, limited utility, and limited investment. Another provider stated aggregate interference calculations seem to be working very well, although the challenge is that it requires sharing among the SAS providers, which has resulted in a slow spectrum sharing transition paradigm. It stated the goal should be real-time sharing, which we are nowhere near today. And one equipment provider discussed that significant research and development resources were spent attempting to find acceptable solutions to the coexistence challenges in early standards/industry organization efforts, but those were ultimately discontinued.

Process Observations and Lessons Learned

Government Stakeholders. Several government stakeholders noted the need for process improvements with CBRS. Two entities (a government operator and a government regulator) indicated there needs to be a clear process to avoid having industry escalate immediately to Congress and the media to force actions without efforts to engage with government stakeholders on potential mitigations. These stakeholders expressed a desire for commercial users to contact the FCC with their concerns, rather than going directly to them. A government lab expressed satisfaction with the engagement between industry and government. A government operator stated the Interagency Joint Working Group (IJWG) process to discuss and approve changes to the CBRS sharing framework has been good but stated there is a need for procedures and terms of reference among DoD, NTIA, and FCC to guide those discussions, noting that the IJWG does not provide a forum for certain necessary classified technical discussions. A government regulator stated better communication may be needed, as some CBRS operators are not getting information that is discussed within the IJWG. The regulator also noted that a lack of communication has resulted in differing perceptions on the federal and industry sides regarding the pace of activity—the government side believes changes are occurring quickly while industry views the pace as delayed (examples here included making the Hawaii DPA a portal-based DPA and reduction of the heartbeat interval). A key lesson learned noted by a government lab is that, when creating a new paradigm, sufficient time (and funding) is necessary for concept exploration, validation, and transition.

CBRS Operators and Their Trade Associations. A fixed wireless association stated: (1) operators should pre-plan for moves to the upper 50 megahertz of CBRS or have alternative paths arranged for move to PAL or other non-DPA affected areas; (2) in the case of Single Frequency Groups (SFGs), the SAS should know in advance that if one CBSD is moved, all of the CBSDs in the SFG need to be moved as well; (3) in non-DPA zones (including non-Portal-DPA), CBRS can be almost always used throughout the entire 150 megahertz when co-existence planning occurs; and (4) operators should coordinate their deployments with SASs and other operators in advance as much as possible. A new entrant wireless provider stated reconciliation between different SAS providers needs more structure and rules after a suspension of commercial operations to accommodate DoD operations has ended. The provider also said it would be helpful to analyze whether the duration of grant suspension due to federal incumbent activity by the SAS can be further minimized, or at least be made more standard. A nationwide wireless provider stated the IJWG process to make proposals on changes to the CBRS sharing mechanisms is working generally but operators don't have a seat at the table—suggesting the potential for operators to listen in without disrupting the discussions between the SAS administrators and the government. The provider also noted the need for implementing changes in a way that is not dependent on voluntary participation and an opportunity for direct negotiations between DoD and industry.

SAS Providers. One SAS provider stated a process should be established to routinely monitor and identify opportunities to improve the CBRS sharing framework, with identified improvements approved and implemented as quickly as possible. Another provider stated the IJWG is inefficient, does not involve enough industry stakeholders, and is in need of higher-level decision-maker meetings. The provider also highlighted that SAS interoperability for data-sharing and CPAS can be slowed down or stopped if a particular SAS decides not to participate or not to cooperate, and that SAS certification should not be "one and done"—rather, SASs should be encouraged (perhaps required) to innovate as a way to improve sharing.

SDOs and Industry Associations. One SAS provider discussed that delays in the initial model adopted by the WInnForum required significant changes in scope, which delayed initial deployment by well over a year, and that these delays could have been mitigated, at least in part, through better communication between the federal users, the regulators, and industry in early phases of planning. Another stated a joint agency engineering working group should get started early in the process of looking at opportunities, challenges, and solutions for new bands. The provider also noted the need for ensuring NTIA/ITS have funding both in advance of an auction and over the life cycle of a band to support sharing.

Equipment Providers. One provider stated the discussion of spectrum sharing is complex and requires a diverse set of experts to properly engage in the discussion, with industry individuals needing access to confidential information; otherwise, a comprehensive analysis of sharing is not possible. Another equipment provider stated the pursuit of higher-level regulatory rules, while leaving innovation by the industry to devise sophisticated solutions, is essential to avoid mistakes that were otherwise experienced with CBRS.

3.4. Standards/Certification

Many commenters recognized that CBRS was new, requiring substantial collaboration among stakeholders, but that the overall process was productive. All commenters who spoke to this issue mentioned that organizations like the WInnForum and the OnGo Alliance played a vital role in establishing baseline technical standards that inform the SAS, ESC, and CBRS equipment. WInnForum was

also mentioned specifically for facilitating participation with all stakeholders, particularly DoD, NTIA, and the FCC. This was helpful working with industry to figure out the implementation challenges and operational security requirements. However, one of the CBRS operators suggested that the issue of GAA coexistence was difficult for SDOs to address due to lack clarity from both a technical and regulatory perspective. This operator recommended that establishing clearer guidelines could provide a better framework for resolving standards. One of the CBRS operators recommended that, due to the complexities of the new sharing paradigm, more education is needed on how to deploy CBRS effectively and appropriately under FCC rules. Another CBRS operator commented that it will be important for the government to continue to participate in the standards process and funds need to be allocated to DoD and NTIA to allow participation.

Regarding certification, most commenters who spoke to this issue mentioned that it was lengthy, complicated, and contributed to a lack of a roadmap to evolve SAS and ESC systems. Commenters also said that having NTIA involved fostered trust for federal incumbents and allowed technically sound and genuine communication between all stakeholders. One of the SAS commenters recommended that the FCC allow self-testing by SAS administrators under the supervision of relevant government entities.

Finally, one of the SDOs recommended that in the future, the FCC and NTIA assess whether there are specific technical issues that may be better defined at the outset by the relevant regulatory agency to more quickly commercialize spectrum and enable timely development and deployment.

4. Considerations for Implementation in Other Bands

How commercial-federal sharing in CBRS can be improved.

The three most common recommendations for improvement to CBRS operations related to: (1) better propagation models, (2) exploration of alternatives to the ESC, and (3) strategies for increasing efficiency by protecting federal operations while reducing unnecessary impacts of DPA events.

Propagation models. The single most frequent recommendation among respondents was to improve propagation modeling. A very wide range of entities—representing the government, both traditional and new-entrant commercial wireless companies, fixed wireless companies, an equipment manufacturer, and an academic expert—stated that current propagation models would benefit from being updated. Respondents recommended that more accurate propagation modeling should account for terrain, clutter, and other factors. One wireless operator recommends a combination of ITU-R P.2108-1[3] for urban/suburban areas and ITU-R P.452[4] for rural areas and suggested that modeling recognize the difference between clutter data and land-category data, with consideration given to the use of LiDAR (light detection and ranging).

Alternatives to the ESC. Another common recommendation was consideration of an alternative to the ESC to maintain protection of federal operations while reducing complexity and unnecessary restrictions of channel availability. Supporters of finding an alternative included traditional and new-entrant wireless companies, two SAS/ESC providers, a manufacturer, and an academic expert. More

[3] Recommendation ITU-R P.2108-1, *Prediction of clutter loss*

[4] Recommendation ITU-R P.452, Prediction of clutter loss, *Prediction procedure for the evaluation of interference between stations on the surface of the Earth at frequencies above about 0.1 GHz*

specifically, a current SAS/ESC respondent recommended a more thorough investigation of the portal concept. And a mobile wireless carrier recommended an AMBIT-like sharing approach, augmented by leveraging advanced RAN interference mitigation capabilities instantiated by: (1) a triggering mechanism like the NTIA-proposed Incumbent Informing Capability, (2) Radio Access Network (RAN)-based sensing of incumbent transmissions, or (3) beaconing from federal incumbent users. Finally, an equipment manufacturer recommended using a SAS-like database mechanism.

Strategies for protecting incumbents while reducing unnecessary impacts of DPA events. Several respondents noted that there are opportunities to maintain careful protection of federal operations while reducing unnecessary and negative impacts of DPA events. Both mobile and fixed wireless providers recommended improving predictability by, where possible, having federal users offer advance notice of "scheduled" DPA events to commercial users. A SAS/ESC provider recommended combining automated portal notifications and ESCs, especially in densely populated areas. A fixed-wireless provider recommended exploration of ways that federal users could reduce the impact of DPA events, including consideration of channel size, antenna directionality, terrain, and clutter—and reservation of the top 50 megahertz for commercial operations where and when the federal user does not need all 100 megahertz. Other respondents recommended: (1) relaxing regulatory constraints to tier-2 and tier-3 operation in non-DPA impacted areas (SAS/ESC provider); (2) optimizing the boundaries of DPA protection areas (commercial wireless provider); (3) adopting requirements to minimize the effect of sensor protections on commercial deployment (i.e. whisper zones) (SAS/ESC provider); (4) consideration of dynamic DPAs in some areas (SAS/ESC provider); (5) conversion of some Portal DPAs to sensor-based DPAs to fix over-scheduling (SAS/ESC provider); and (6) recognition that a suspension of operations in a DPA is not typically necessary for indoor equipment (fixed-wireless provider).

Other suggestions. Respondents also provided several other suggestions for improvements to CBRS operations.

- Synchronizing uplink/downlink: An academic expert noted that experiments demonstrate that synchronizing uplink and downlink transmissions would substantially increase utility.
- Increased power: An equipment provider, two nationwide mobile network operators, and their industry association, and a new-entrant operator recommended that the FCC increase the maximum permitted power for the CBRS band and relax the OOBE limit as current power levels reduced the utility of operations in the band.
- Aggregate interference: Traditional and new-entrant wireless companies and an academic expert recommended either eliminating or revising aggregate interference calculations.
- Transmit expire time: A wireless provider recommended increasing the transmit expire time.
- Heartbeat-timer requirement: Both a SAS/ESC provider and a fixed-wireless provider recommended reduction of the five-minute heartbeat timer requirement.
- Better communication: Two trade organizations recommended expanding communications on CBRS development beyond government coordination with SAS/ESC providers to include CBRS band operators and vendors.
- Operational improvement by SAS/ESC providers: Several respondents noted ways that SAS/ESC operators could improve operations, including: (1) addressing backhaul issues during extreme weather events, (2) faster channel switching when there is a DPA activation, (3) use of better algorithms to provide optimized channels when under suspension (as this is mandatory for mission critical applications), and (4) including measurements from the RF environment from CBSDs in SAS calculations.

- Improving sensing operations: A wireless provider recommended: (1) relaxing stringent operational security requirements to increase the efficiency of sensor deployments (specifically, a reduction of the propagation reliability requirement of 95% to median), and (2) the use of interference mitigation techniques in the sensor radio to overcome the effects of Whisper Zones.
- Certification: A wireless provider recommended ensuring that any changes to SAS operations do not trigger a repeat of the ITS certification testing process.

Elements of the CBRS non-federal and federal spectrum sharing experience that should be considered for implementation in other bands/cases.

Two government respondents, two new-entrant wireless companies, three SAS/ESC providers, an educational institution using the CBRS band for its operations, and an academic expert recommended that the U.S. extend the CBRS framework to other bands. Several respondents noted that while the CBRS framework provides a strong foundation of future shared bands, implementation should consider the particular characteristics of that band and its incumbent users.

More specifically: (1) a SAS/ESC provider recommended that it was important that future shared bands include all three tiers found in the CBRS band (incumbents, PALs, and GAA), that the presence of the GAA tier produces more robust use of the band, and that the lack of a GAA tier undermined sharing in the European Union, (2) an academic expert noted that the lower power level in the CBRS band is advantageous for effective sharing in future shared bands and that the CBRS framework has allowed small- and mid-sized deployments of community networks, (3) a SAS/ESC provider noted that it will be important that the U.S. adopt mechanisms for future bands that permit spectrum access by more than only nationwide wireless companies.

More broadly, a government operator recommended that the U.S. establish sharing and/or co-existence as a key priority. To further this prioritization, a new-entrant wireless provider and a SAS/ESC provider recommend that in considering future bands the U.S. would benefit from public-private collaborations such as the PATHSS (Partnering to Advance Trusted and Holistic Spectrum Solution) task group process. A mobile wireless company recommends that, in any discussions between government and commercial users about a future band, the government implement a method of sharing classified federal and non-federal NDA network data.

Several respondents recommended that the U.S. expand spectrum sharing using the CBRS framework to particular frequency bands. The most frequent recommendation among those supporting this suggestion was that the U.S. adopt a CBRS-like sharing framework in the 3.1 GHz band—multiple new-entrant wireless companies, a fixed wireless provider, a SAS/ESC provider, a trade association, and an academic expert each identified this band. Other bands identified for potential CBRS sharing were the 7-8 GHz band (and, for a different respondent, a larger 7-11 GHz frequency range), the 10.0-10.5 GHz band, the 12.7-13.25 GHz band, the 15 GHz band, the 37-37.6 GHz band, and the 42-42.5 GHz band.

Elements of the CBRS non-federal and federal spectrum sharing experience that should be avoided in other bands/cases.

Two nationwide mobile wireless providers, a trade association, and an equipment manufacturer recommend against implementing a CBRS-like framework in other bands. Specifically, they responded that the lower powers, smaller license areas, and preemptability of the CBRS framework renders the band less suitable for nationwide wireless coverage networks and limits its use cases, thereby reducing

investment and deployment, and diverges from global standard and deployment scenarios for traditional mobile wireless networks. Instead, the association recommends use of a "static sharing" approach in future bands in which a frequency range is auctioned, and auction resources are used to relocate incumbent government users. A nationwide provider recommended that the CBRS model itself should be avoided, stating it minimizes the utility of the band as compared to other shared spectrum models such as the Advanced Wireless Service and AMBIT frequencies. The same provider stated that CBRS and other shared frameworks are not immune to interference from high-power radar systems and that the CBRS model is not workable in a multi-radar environment. It recommended that a future sharing solution should be between incumbent Federal users and licensed commercial users (i.e., static licenses), with as high power as possible in the specific license area, rather than CBRS that uses the same very low power in all areas even if not required for federal interference protection. Another nationwide wireless provider recommends that if the U.S. nonetheless decides on a CBRS-like sharing approach, it should: (1) include only two tiers: incumbents and PALs; (2) grant commercial users co-primary status with government users and establish a shared responsibility for each to protect the other's systems; (3) distinguish between essential primary federal use cases and secondary "beneficial" use cases when determining incumbent protection; and (4) develop an open-source analytical model that is informed by, and calibrated and evaluated against, real-world performance benchmarks for both incumbent and new entrant systems.

Several respondents reported that the CBRS band has been successful, support implementing a CBRS-like framework in other bands, and also suggest changes that would produce improvements. (1) Many respondents recommend that any future shared bands should not implement a sensing network like the ESC. A mobile wireless respondent, a fixed wireless respondent, a SAS/ESC provider, and an academic expert each recommended adopting an alternative approach. Multiple respondents recommended the use of a portal approach rather than sensing. (2) A government regulator noted that it will be important to extend the updates to propagation models discussed in the context of the CBRS band for use in other bands. (3) A SAS/ESC provider recommended that the U.S. should make coexistence among commercial users (both GAA and PALs), in addition to coexistence between government and commercial users, a fundamental consideration in future sharing frameworks and that the FCC's Part 96 rules lack sufficient guidance to define and encourage such coexistence. (4) A SAS/ESC provider recommended that the FCC optimize ULS to better support shared spectrum frameworks because ULS data is often incomplete, inaccurate, and/or lacks required information to perform more accurate interference analyses in shared bands. (5) An association suggests establishing incentives for commercial users of shared bands to report to database providers on information about the RF environment that they learn through their operations, as this will make spectrum usage more efficient (noting that there is no benefit for such reporting today). (6) An equipment provider recommends establishing incentives for parties to compromise in standards bodies and industry organizations, as this will lead to the best technical solutions in future bands.

5. CSMAC Recommendations

The CBRS band provides a unique opportunity to allow various non-federal entities to coexist with federal incumbents and other commercial users within a hybrid licensing mechanism, permitting a wide range of use cases across various users including fixed and mobile wireless operators, equipment vendors, and enterprise users. CBRS utilizes unique solutions (such as a SAS) to address its three-tiered sharing framework. Across all stakeholders it was unanimously felt that the hybrid CBRS framework has resulted in commercial use without harmful interference to federal radiolocation and federal aeronautical radionavigation incumbents and that the lessons learned have been valuable to help fine tune this approach for the future. Considering that the SAS/ESC sharing framework is new, there should be a

better process to address improvements. No defined process currently exists, and any suggested improvements are slow to address and implement.

The following specific recommendations are proposed by the CSMAC:

A. Create a process with all federal, commercial, NTIA, and FCC stakeholders to drive timely improvements to rules, operational settings, and standards as applicable. This process could inform the soon-to-be-created Interagency Spectrum Advisory Council as mentioned in NTIA's National Spectrum Strategy. The process should consider the following details:
    1. Hold quarterly policy group meetings, chaired by the NTIA, to identify policy improvements to CBRS and move them forward.
    2. The policy group should be comprised of federal and industry stakeholders with the involvement of the FCC.
        a. Federal members should be senior enough to coordinate their organization's views and move issues forward.
        b. Industry members should include PAL and GAA users (both commercial and non-profit), equipment vendors, and SAS operators, and relevant associations affiliated with each of these groups. Industry members should be senior enough to coordinate their organization's views and move issues forward.
        c. For example, if industry brings the concern of: "Resolving the reservation of excessive amounts of spectrum for longer than expected periods during federal events," then the policy group will engage the federal agencies to resolve this concern.
    3. To the extent the CBRS framework is adopted for other frequency range(s), the policy group framework and its stakeholder composition would need to be tailored to fit the unique circumstances of that frequency. The policy group framework may have to adjust to include additional equipment and system manufacturers impacted, to include wireless, defense, and any other relevant equipment sector.

B. Additional recommendations based on stakeholder feedback include:
    1. Updating the propagation model, methodology, and use of clutter and building data.
    2. Deciding between ESCs and their inherent limitations (e.g., Whisper Zones) or incumbent informing solutions (e.g., IIC, TARDyS3).
    3. Reducing complexity of the process of the aggregate interference protection to lower the computational load on SASs so that the SASs can grant channel assignments approaching near real-time. For example, aggregate interference calculation methodology should be improved by reducing the reliability requirement from 95% to median.
    4. Reducing DPA Neighborhood sizes.
    5. Reducing the heartbeat interval in non-DPA areas.
    6. Reducing the DPA activation timer.
    7. Resolving the reservation of excessive amounts of spectrum for excessive lengths of time by federal users through portals.
    8. Improving advanced notification of scheduled events to the commercial end user, particularly with regard to timing, pervasiveness (both in terms of frequency and geography), and coordination.
    9. Studying the impact on federal operations of increasing maximum EIRP levels.

C. When considering the FCC rules regarding the sharing of spectrum between non-federal users and federal incumbents, NTIA should collaborate with the FCC, industry, and government stakeholders early to assist the FCC in developing better sharing methodologies. For example, sharing mechanisms should be automated where possible.
D. Given that spectrum sharing requires a commitment of resources by federal agencies, NTIA should advocate to ensure that the impacted federal agencies are adequately funded to support ongoing spectrum management and sharing activities, outside of the Spectrum Relocation Fund process.