

Decolonizing Dynamic Spectrum Sharing

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Abstract: Spectrum sharing, including dynamic spectrum sharing, is arguably the most significant overarching feature of the new era of spectrum management. The emphasis on sharing spectrum recognizes the importance of balancing the needs of different users of an exceptionally valuable resource. Despite the equitable features of spectrum sharing, what has been underemphasized in spectrum management is its colonial features from the perspective of Native Nations. This paper proposes ways to decolonize dynamic spectrum sharing and, in the process, improve prospects for a new spectrum era that recognizes Native Nations as collaborators in the American system of spectrum management.

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Introduction

...[C]ontrol by indigenous peoples over developments affecting them and their lands, territories and resources will enable them to maintain and strengthen their institutions, cultures and traditions, and to promote their development in accordance with their aspirations and needs.

- United Nations Declaration of the Rights of Indigenous Peoples (2018)

Spectrum is a tremendously valuable resource. It is valuable for commercial broadcast, as evidenced by the tens of billions of dollars industry has paid for rights of broadcast over the past two decades. It is valuable for government functions, including public broadcasting and national security. It is valuable for radio astronomers who “visualize” outer space through radio waves.

The value of spectrum is one of the reasons why it is necessary to manage spectrum. The conventional story of spectrum management in the United States is an optimistic one of gradual progress in improving access to spectrum management. The brief version of the story is that the first spectrum era, from the time Guglielmo Marconi first transmitted information over the airwaves until the early 1920s, was a period of anarchy. In the context of spectrum, anarchy refers to many people transmitting, especially commercial broadcasters, without any overarching set of rules to determine when and how people manage active radio frequency (RF) transmissions. Congress stepped in with the Radio Act in 1927. Most significantly, the Radio Act specified that Congress and Congress alone would have the authority to manage spectrum in “public interest.” A few years later, in 1934, Congress established the Federal Communications Commission (FCC) to handle the business of managing spectrum. It did so by establishing a system of committee hearings to determine who could use the spectrum and at what times. Though spectrum policy luminaries such as Leo Herzog and Ronald Coase recognized some of the limitations with the committee system (or “beauty contests”) to allocate licenses to spectrum, the liberal era of spectrum management, with its emphasis on allocation of licenses through competitive auctions, did not firmly emerge until the 1990s. The new era is one where spectrum sharing, including dynamic spectrum sharing, is recognized as the key to continued progress in spectrum management.

Spectrum sharing recognizes that there are many users who want spectrum, and hence the spectrum management regime should focus on increasing opportunities to share spectrum, which is a finite natural resource. This emphasis on improving the efficiency of spectrum and equity of access to spectrum, in a sense provides the best of both worlds:

auctions remain a significant feature of spectrum management, though there is increasing effort to establish arrangements where spectrum from the outset is considered a shared resource. Attention is increasingly dedicated to support for new technologies to facilitate sharing spectrum, as well as to create a regulatory and legal framework to encourage spectrum sharing.

Despite these benefits, we argue in this paper that the existing spectrum regime in the US, including spectrum sharing, has always had colonial features. This perspective becomes clear when we center the experience of Native Nations and indigenous and tribal communities in the spectrum management regime. Colonial institutions included direct control of colonies by European powers, as well as the influence of Europe on the rest of the world. In the Americas, colonial institutions included the long process of removing and subjugating Native Nations. One of the most significant institutional basis, which can be traced to the Doctrine of Discovery and the view that America was *terra nullius*, is the assumed supremacy of the federal government over Native Nations. While this principle has been understood as a feature of Native-White relations since the Declaration of Independence (which refers to Indigenous peoples as “Merciless Indian Savages”), its vestiges in how spectrum policy was established and implemented on Indigenous homelands and ancestral lands is only recently becoming explicit in the history of US spectrum management policy and consideration of its future.

The United Nations Declaration of the Right of Indigenous Peoples recognizes the importance of meaningful autonomy and control of Indigenous Peoples to manage their resources. The value of spectrum has not been accompanied by recognition of the rights of Native Nations to manage this valuable resource, nor of establishing a specific role for sovereign Native Nations in the broader efforts to establish frameworks to share spectrum. Our goal is to describe these key features in a constructive way in the sense that we believe there are systematic ways to decolonize spectrum management. Because spectrum sharing is the defining feature of the new era of spectrum management, we devote special attention to decolonizing dynamic spectrum sharing.

The Conventional Story of Spectrum Management

The time before the Radio Act is often described as “anarchy.” It was anarchy in the sense that for most transmissions, there was no overarching government in place governing the use of spectrum. This did not mean there were no rules. The common law, which includes laws to govern various aspects of business, was considered to resolve issues when broadcasters came into conflict with one another (Douglas 1987; Huber 1997). The

government had also, in the 1910s, created rules to manage communications over the airwaves to minimize interference with Naval transmissions.

Anarchy, in this sense, recognizes that there were some rules to govern RF use, though there was no overarching, centralized system of coordination. To borrow the language of Thomas Hobbes, who in 1651 famously described life without a sovereign as “short, brutish, and nasty.” For Hobbes, “there be no propriety, no dominion, no mine and thine distinct; but only that to be every man’s what he can get,” without Leviathan, which the name he used for an all-powerful government.

Hobbes’ account sounds sort of like use of RF before the Radio Act, where everyone in a sense owned it and so nobody owned it. This perception that national-level coordination was necessary is what led to the Radio Act and, soon after, the creation of the FCC. The FCC had to allocate spectrum, which they did through committee hearings. These hearings, which were called beauty contests because the commissioners had to judge broadcasters like a pageant, were effective in managing interference because they were able to give different companies rights over frequencies, along with a cushion around those bands to prevent interference. Herzel and Coase pointed out that the committees assigning rights have a challenging time figuring out who values spectrum the most, and perhaps more importantly from a political perspective, the government was not capturing much of the economic value of spectrum (Herzel 1998; Coase 1959). Efficiency was a problem because those who had the licenses were not necessarily the ones who valued them the most. It took several decades, but by the early 1990s, the FCC came around to auctioning licenses to spectrum. The cellular marketplace, for example, has been able to meet demand in large measure because the rules governing it have become more decentralized and market-oriented, starting in the 1980s (Hazlett, Palida, and Weiss 2023).

This shift was “liberal” in the sense of classical liberal economics, with its emphasis on the use of markets to allocate resources to promote the common good. Liberal licensing emphasizes the improvements in spectrum management through markets. One of the goals of liberal licensing is to create more property rights and more markets. The “anticommons” of spectrum describes situations when multiple stakeholders with overlapping claims and regulatory barriers prevent effective use and development of spectrum resources (Hazlett 2005). The tragedy of the anticommons is when valuable spectrum lies fallow because of excessive regulation and competing interests. A solution is clearer, more streamlined property rights and market mechanisms to allocate them.

Television white spaces are an example of how auctions can improve spectrum management (Hazlett 2011). When TV companies received their allocation, they had a buffer, or white space, around it. As technology to reduce interference improved (mainly

through making better receivers), and especially once cable became prominent, those white spaces could be reallocated. Markets were eventually useful in doing so, though as is common in spectrum more generally, political conflict and challenges led to significant delays in developing a more efficient way to allocate the white space which was for decades considered a “wasteland” (Hazlett 2017; Werbach 2011).

The liberal licensing regime was not the end of the spectrum story. American spectrum management is now in what can be called a sharing era, one which takes as a starting point that there are somewhat permanent conflicts of interest in how to use spectrum. Many of these conflicts involve government entities. Government uses spectrum for many of its functions, including public safety, law enforcement, border protection, and military defense. Wireless companies also have a seemingly unquenchable thirst for spectrum, often the same bands that government entities want.

Sharing spectrum is seen as the way to balance these competing interests. In 2012, the President’s Council of Advisors on Science and Technology (PCAST) released its well-known report on spectrum sharing, “Realizing the Full Potential of Government-Held Spectrum to Spur Economic Growth.” Soon after, the FCC proposed new rules governing wireless broadband providers to share airwaves with government users. The hope was that sharing spectrum could increase productivity, jobs, and innovation, while protecting essential government systems. Unlike the liberal licensing regime, where the government’s role is mainly to issue licenses (which serve as “property rights” to spectrum) and decide on the specific rules for auctions, spectrum sharing sees government, industry, and everyone else as partners in the use of spectrum and the effective management of spectrum as co-produced by government, business, and civil society.

The gradual improvements and refinements in spectrum management do not address all challenges. Radio pirates, which refers to any individuals or groups who engage in unauthorized radio transmission, have long questioned the seemingly draconian FCC enforcement of rules about using the airwaves when it seems they are not harming anyone (Dunbar-Hester 2014). There is also a longstanding question about passive users who require quiet zones and whose ability to use radio telescopes is made more challenging with more transmissions, including with the increasingly crowded low-earth orbit and the rise of megaconstellations of satellites (Weiss et al 2021). Hence, the conversation about how to provide for more efficient and equitable use is an ongoing one, despite arguably substantial progress in the governance of spectrum in the US.

In these conversations about improving the spectrum management, Native Nations are often an afterthought. The FCC has not completely ignored Native Nations, perhaps most notably with the Rural Tribal Priority Window (RTPW), which in 2020 freed up valuable

midband spectrum for federally recognized tribes in rural areas. But this gesture alone did not change the FCC's general spectrum policy outlook relating to Native Nations, which is overall disempowering and does not offer any acknowledgement of tribal sovereignty.

From Subjugation to Sovereignty

The colonial features of American spectrum management policy are a consequence of the more general colonial aspects of federal relations with Native Nations. These features were present from the outset of the United States, including the Declaration of Independence of 1776 and subsequently in the Constitution, which granted Congress was given authority to "regulate commerce" with Indian tribes. The Constitution's so-called "Indian commerce clause" was the basis for Congress regulating essentially any economic activity in Indian Country. The Supreme Court, in the 1830s, legally cemented the authority of Congress over Native Nations. The key decisions, known as the "Marshall trilogy" for the Chief Justice John Marshall, who wrote the majority opinion in the foundational cases, established a paternalistic relationship between the federal government and Indian Nations as a relationship of a ward to its guardian.

Alongside the establishment of subservience through constitutional rules, policies were used to subjugate Native Nations. The list is too long to mention here. Some of the most significant legislation of the 19th century included the Indian Removal Act of 1830, which authorized the violent deportation of all Indigenous peoples living in the south and east to new homes west of the Mississippi River and the Dawes Act, which in 1887 established a burdensome framework to govern Indian reservations. Before the US Civil War, the federal government signed 374 treaties with Native Nations, though after the Civil War, the government largely abandoned treaties, shifting its emphasis to the eradication, containment, and assimilation of Native peoples. The Homestead Act of 1863, which was hailed by white settlers as standing for the principle of "free soil, free men," was also used to create a flood of settlers to reduce the costs of policing the frontier (Allen 1991).

Indigenous groups in the Plains were able to successfully fight the US armed forces and evade troops for decades, but by the end of the 19th century, most Indigenous people were living on reservations under the coercive rules of the Dawes Act. The Dawes Act was largely a failure in its stated objectives of promoting economic development on Indian reservations. One of the goals of the Dawes Act was to convert reservation land to private property, which it was successful at, resulting in major dispossession of Indigenous homelands. The government did this in part by established burdensome processes for Indigenous people to acquire legal title, including requirements of demonstrating

“competence” and a 25-year period before an Indian¹ could secure free and clear title to their land. An Indian could demonstrate competence by giving up their culture and agreeing to abide by the norms and values of White society. “Excess land” not allotted to Indians was opened for white settlers to claim. It’s estimated that Indigenous peoples within the present day US lost 90 million acres as a result of the Dawes Act. On the land still held by Indians there were fragmented, ineffective property relations (Shoemaker 2003). The government, especially the Bureau of Indian Affairs, largely crushed economic opportunities to farm because they imposed many burdens on land, including restrictions on selling land and a major constraint on how much land an Indian could own (McChesney 1990). The Dawes Era also established boarding schools which were explicitly designed to devastate Indigenous cultures under the guise of promoting economic development.

In 1934, the government attempted to improve governance of reservations with the Indian Reorganization Act (IRA). This law locked already heavily diminished reservation land in place, stopping the bleed of land loss that had been a persistent feature of the Dawes Era (Miller 2018). However, the IRA also imposed substantial restrictions on economic activity, and set up colonial-mirroring tribal government structures with boiler-plate constitutions that required federal approval for any substantial actions or changes made by tribal governments. This included tremendous oversight over Indian country trade, property, and contract relations. Under this system, any Indian seeking to do business had, as a legal matter, to get permission from federal bureaucrats to do so, and the rules themselves provided almost no autonomy for Native Nations to develop their own rules and government structures to govern their reservations.

By this time, the overarching feature of policy was cultural devastation (Lear 2006). Government policy believed White institutions were the way to development, and self-determination was largely absent as a matter of federal policy (Anderson, Benson, and Flanagan 2006). In the IRA era, there was no question that federal governance was paternalistic, however, federal policy still recognized tribal governments as distinct peoples with individual governing bodies and a degree of sovereignty over internal affairs. This changed during the Termination Era, which in the 1950s attempted to undermine the very foundation of reservations and eradicate any semblance of tribal sovereignty by forcing Native Nations into the political, economic, and legal institutions of the state governments.

The situation finally changed in the 1970s, when Richard Nixon announced that the federal government would take the sovereignty of Native Nations seriously. This shift brought us into the current era of federal Indian policy, known as the self-determination era. Since the

¹ we use the term “Indian” aligning with the federal legal definition found in 25 USC 2201(2)

1970s, federal policies have made significant shifts to acknowledge the sovereignty and self-determination of Native Nations. Despite much progress, the same institutions and bedrock principles that subjugated Indigenous peoples and established absolute federal power over Native Nations remain “good law” in the sense they are still legal precedent. This means that despite substantial progress in recognizing tribal sovereignty, from a legal perspective, Congress still has plenary authority over Native Nations, and the federal government still manages a tremendous number of activities in Indian Country.

Centering Native Nations in US Spectrum Policy

From the perspective of Native Nations, there has been a single spectrum era: one in which the FCC has essentially all authority over spectrum. From 1927 onwards, the FCC has been the overarching authority over spectrum. Its monocentric features have led to thought experiments about what it would mean to abolish the FCC (Hazlett 2008).

The monocentric features of spectrum have also been highlighted by the recent movements for Indigenous and tribal spectrum sovereignty. These are global movements of Indigenous and tribal peoples, including movements of Māori to secure more rights to frequencies in New Zealand, First Nations of Canada to secure more access to valuable spectrum bands, and the struggle in Guatemala for rights for Indigenous communities interested in use of airwaves for community radio (Howell and Tang 2023; Hudson and McMahon 2022). These global movements for spectrum sovereignty share a recognition that spectrum management regimes are in general highly centralized and have traditionally excluded specific rights for Indigenous and tribal peoples (Blackwater, Murtazashvili, and Weiss 2024).

In the US, Indigenous and tribal spectrum sovereignty movements contributed to consideration of the DIGITAL Reservations Act. This legislation, which was sponsored by Senator Elizabeth Warren and then-Congresswoman Deb Haaland, would have returned authority over Native Nations to manage spectrum. In this regard, it had the potential to contribute to 574 “mini-FCCs,” though the legislation emphasized that Native Nations could opt into federal management through the FCC, while still benefiting from the spectrum on their lands (Blackwater, Murtazashvili, and Weiss 2023).

There are several features of the DIGITAL Reservations Act that are important to mention. One is that it recognizes the centralization of federal control conflicts with the sovereignty of Native Nations. Since Native Nations are sovereign, the federal government has an obligation to recognize their authority over those resources (Blackwater 2020). Despite this, the FCC enjoys a monopoly on how spectrum, a valuable natural resource, is

managed on tribal lands, and shares none of the revenue collected from the sales of tribal resources.

The DIGITAL Reservations Act, by recognizing the broader power dynamics in spectrum management, extends beyond previous FCC policies to improve access to spectrum on tribal lands. The Rural Tribal Priority Window provides such access, but it is to only a very limited part of the spectrum, and to date, it has not been extended. In addition, there were challenges with how it was implemented, as very few tribal entities made use of these opportunities. Native Nations do **not** have the authority to auction licenses on tribal lands, nor do they have specific claims over the revenue from auctions.

Another issue is that it is not clear that Native Nations have the authority to experiment with new ways to improve spectrum access. One of the features of spectrum is that new technologies can often have major impacts on how spectrum is used, including the ability to share spectrum. The challenge is that the FCC may not always be as responsive to enabling experimentation in new technologies.

Spectrum sovereignty would recognize autonomy for Native Nations to provide for such experiments, provided they want to do so. For example, Dewayne Hendricks worked to extend the possibilities of spectrum management, partnering with the Turtle Creek Band of Chippewa Indians on deployment of new technologies to provide greater broadband access (Hurtig 2002). However, since Hendricks' work two decades ago, there has been little movement to overcome the Dark Ages of spectrum on reservations, and as a result, Indian Country remains the least connected areas in the US (Bauer, Feir, and Gregg 2022).

Colonial aspects of governance are also present with passive use. Radio astronomy is one of the fundamental "passive" users of spectrum. There are several ways in which radio astronomy confronts some legacies of colonialism. One is through location. The valuable quiet zones that are a key to radio astronomy and the space telescopes are often located near reservations due to the rural and sparsely-populated nature of these lands. Radio astronomy sites are always on ancestral homelands, and often on sacred sites, yet Native Nations have rarely been consulted in site-selection processes.

An example is the Green Bank Observatory. Today, there is an acknowledgement of ancestral lands at an official level. But in one of the histories of the site selection process for Green Bank Observatory, the only information close to recognition that the observatory sits on Indigenous homelands was that it is located in "Pocahontas County."²

² According to "Telescopes on Stolen Land", the Green Bank Observatory is on the homelands of the Moneton, Calicua, and Monacan peoples.

When a radio astronomy site is near, there are major obligations placed on tribal citizens and Native Nations. Quiet zones require a substantial commitment from all users to not transmit. This means that any telescope near a reservation requires coordination with Native Nations.

Decolonizing Dynamic Spectrum Sharing

Spectrum sharing refers to cooperative arrangements that balance the diverse needs of spectrum users to ensure that all stakeholders have access to spectrum and that it is used efficiently. Spectrum sharing arrangements enable multiple parties to use the same spectrum by implementing rules and mechanisms governing access. These include dynamic spectrum access systems, policies for creating exclusion zones, and systems to detect events and interference to enable mitigation with multiple users accessing the same frequency bands. Spectrum is a limited resource, referred to in economic theory as “a commons” because it is subject to congestion and competition. It is in high demand for various forms of wireless communication including broadcasting, mobile telephony, satellite communication, and radio astronomy, and much more.

Because spectrum licenses are based in time, frequency, and geography, any sale or allocation of spectrum licenses on tribal lands should trigger a flurry of federal consultation, consent, and compensation obligations. Generalized spectrum sharing architectures manage access to spectrum from a geospatial and temporal perspective. Geospatial (or spatial) access coordination refers to a specific location area: a canonical example is the sharing of FM (or AM) radio transmission based on locality and radio station signal propagation characteristics. Consider the FM radio band and choose a specific FM transmission frequency of 97.3 MHz: there are multiple FM stations across the United States that broadcast at 97.3 MHz (e.g., KBCO in Denver/Boulder CO; KWFM in San Diego, CA; KIRO in Seattle, WA; HITS in Miami, FL; and several more across the country). There are multiple 97.3 MHz FM license holders that are separated in space (geographical location) such that their signal transmissions do not overlap – thus spectrum is allocated and shared spatially. If there were FM stations in the same location (e.g., in Boulder/Denver), then the spectrum would need to be shared in time (temporally) with each radio station transmitting in alternative time slots (this doesn’t work for streaming audio transmission but is how wireless data transmission sharing is accomplished).

Spectrum access and management systems exist both commercially and for the Department of Defense (DoD). DoD spectrum access systems include the Operational Spectrum Comprehension, Analytics, and Response (OSCAR) Solution for Dynamic Spectrum Management (OSCAR Overview), the Multiband Control Channel Architecture

(MICCA, M.D. Silvus), and the National Spectrum Consortium, NSC, Partnership to Advance Trusted and Holistic Spectrum Solutions (PATHSS, David Mueller). Commercial spectrum sharing systems are led by the WinnForum Spectrum Access System (SAS, WINNF-TS-0112), the Winn Forum and Wi-Fi Alliance Automated Frequency Controller (AFC, WINNF-TS-4007), along with the University of Utah's open-source spectrum zone management system (OpenZMS). A federal recognition of spectrum sovereignty would require each of these entities to change policies, but each of these entities may have the authority to begin the process of recognizing Indigenous spectrum rights on their own at any given time.

For an introduction to coordinated spectrum sharing consider the WinnForum CBRS Spectrum Access System (SAS). Citizens Broadband Radio Service (CBRS), which was launched in 2020, was one of the initial sharing models. The structure of CBRS includes incumbent users and secondary users, including priority and general access users. CBRS incorporates dynamic spectrum sharing (DSS), which allows for real-time sharing of spectrum bands among multiple users. The US Navy is the incumbent user, and commercial users can use spectrum when the Navy is not using it. Commercial access to CBRS spectrum was allocated through auctions, with around \$4.6 billion bid, mostly by mega-communications providers such as Charter, Dish, and Verizon (Berry et al 2023).

The SAS (Spectrum Access System) allocates frequency channels to CBRS access points (also known as CBSDs) transmitting in the 3.5 GHz band. Citizens Broadband Radio Service (CBRS) is a new spectrum service for indoor and outdoor Wi-Fi communications in the 3550-3700 MHz band allocated for private use by the FCC. This band was previously only used by the United States Navy and Airforce. Due to underutilization, the FCC opened the 3.5 GHz band for broadband private use. Spectrum sharing is organized across three tiers, with a SAS administrator providing priority to the top tier, while preventing interference to lower tiers. Technologies like SAS dynamically adjust which users can access the spectrum based on current conditions. Through such arrangements, multiple users coexist in the same spectrum band by adjusting their access based on real-time conditions. Primary users retain priority and protection for their operations, while secondary users can utilize spectrum when it is not being used by the primary users.

The CBRS spectrum is divided into three tiers: Incumbents, Priority Access, (PAL) and General Authorized Access (GAA).

- **Incumbents:** Reserved for governmental agencies, Navy ships, and fixed satellite stations. Nothing is allowed to interfere.

- **Priority Access License:** Licenses that are for commercial business use and acquired through CBRS auctions, in case priority of way is required for up to 40MHz per county, assigned on a per access point (CBSD) basis.
- **General Authorized Access:** GAA is the third tier on the CBRS, and ideal for private deployments. Devices in this range can include mobile and IoT devices that are commonly used within enterprise environments.

In order to protect the first two tiers from interference, mobile network operators and enterprise private LTE / 5G deployments must use a Spectrum Access System (SAS) to ensure that their devices do not cause interference and adhere to the FCC regulations. This helps protect your devices on the CBRS network from unlawful interference.

The Spectrum Access System (SAS) is an autonomous cloud-based radio spectrum coordinator that manages wireless communications operating in the CBRS spectrum. Devices register with the SAS for spectrum assignment and moderation of their power transmit levels.

Devices operating on the CBRS spectrum are called CBRS Service Devices (CBSDs). Each CBSD needs authorization from the SAS before they begin transmitting data. Currently, there are several companies approved that provide SAS administration from which IT teams can choose from including Google and Federated Wireless.³

The SAS uses Environmental Sensing Capability (ESC) sensors to enforce FCC rules, manage spectrum allocation, and prevent radio interference. These ESC sensors are located across the United States, primarily along the coastline where they detect broadcasts over the CBRS spectrum. These sensors protect the Incumbent tier from interference, specifically Navy ships located off the coast.

When the ECS detects an incoming transmission on the Incumbent tier, it automatically creates a protection zone in that area to prevent interference from any other sources. Rather than blocking all communication in that zone, the SAS dynamically reroutes PAL and GAA users to other bands of the spectrum so incumbents can communicate without interference.

Devices using the CBRS must reach out to the SAS prior to broadcasting. Currently, the SAS cannot proactively detect and communicate to a device, so that device must contact the SAS on its own. CBSDs can communicate with a SAS either directly or by using a Domain Proxy. Domain Proxies act as an intermediary between the SAS and devices

³ <https://cb.rs.wirelessinnovation.org/sas-administrators>

sending requests. There are currently six different ways a CBSD can communicate with a SAS.

- **Registration:** The CBSD shares device information with the SAS. In exchange, the SAS provides that device with a unique identifier and access.
- **Spectrum Inquiry:** The CBSD sends the SAS a spectrum inquiry request to learn which parts of the spectrum are currently available. The SAS provides the best options available.
- **Grant Request:** The device will send a request to operate on a particular frequency to the SAS. The SAS will deny the request if that communication may interfere with incumbents. If approved, the SAS will grant the device a grant ID.
- **Heartbeat Request:** The CBSD will send out multiple heartbeat requests to the SAS for each of their approved grants. Devices must be issued a grant ID prior to getting permission to transmit. If approved, the device can transmit until the transmit expire time, which is typically 240 seconds after the last heartbeat.
- **De-registration:** If the device is being moved or retired, it will deregister itself from the SAS.
- **Relinquish Grant:** When the device no longer needs the grant to operate, it relinquishes the grant.

These requests can be sent by using a SAS portal or done automatically using an API integration with a SAS administrator.

The SAS protects incumbents by maintaining a database of all CBRS devices, their locations, access level, and unique identifiers. Combined with real-time sensor data the SAS can adjust spectrum availability and broadcast power assignments using the latest information in real time.

To ensure all SAS administrators have the latest information, each SAS performs a nightly export of all data. This process is called Coordinated Periodic Activities (CPA), and occurs synchronously for all spectrum access system servers.

One spectrum sharing management option for Native Nations may include a minimalist model of inclusion in DSS. Under the minimalist model, Native Nations are considered secondary users in any DSS arrangement that involves spectrum on tribal lands. While this option still puts Native citizens in a secondary role, and therefore does not align with the definition of spectrum sovereignty, this option would offer Indigenous peoples greater access to spectrum on tribal lands.

Another option is a more extensive model of integration that better aligns with tribal sovereignty. Under the extensive model, Native Nations would become the priority users in a DSS system. This could involve a CBRS deployment on tribal lands in central (non-coastal) US. In this scenario, the Native Nation is the incumbent (and could potentially choose to share its incumbency role for profit). Additionally, the tribal government could auction Priority Access License(s) (PALs) for mid-priority users and control General Authorized Access (GAA) users' third-tier access for profit as well. This model would empower Native Nations to manage 3550 MHz to 3700 MHz as a pathfinder/exemplar in a specific geolocation. Furthermore, the CBRS equipment providers, support personnel and operations personnel would be Native Nations focused from a workforce development (WFD) perspective, further building management capacity on tribal lands. There may be overarching security considerations, but the priority users and beneficiaries of spectrum on tribal lands would be the Native Nation itself and its citizens, which is the true essence of spectrum sovereignty.

Decolonizing Radio Astronomy

The impact of radio astronomy is profound. But it has challenges in its relationship to and respect toward Native Nations. The Very Large Array (VLA) is hailed for its contribution to scientific exploration. Still, it is not always clear that there was authority to set up those telescopes. This has more generally been described as the problem of telescopes on stolen land.⁴ Essentially all radio astronomy telescopes are on land claimed as ancestral lands by Native Nations, and in some instances, those telescopes are on or adjacent to tribal lands.

This is a significant issue when we consider the Next Generation Very Large Array (ngVLA). The ngVLA is a prime example of dynamic spectrum sharing. The National Radio Dynamic Zone (NRDZ) creates zones of radio frequency that are used dynamically to protect sensitive astronomical observations from interference. In these zones, spectrum is shared with different users, including radio astronomers and other spectrum users, to minimize interference and maximize spectrum efficiency. Through such processes, it is hoped that radio frequency will be used more efficiently and equitably, in this case by recognizing the needs of the radio astronomy community which is a passive user who depends on "landscape" rights that involve radio frequency (RF) quietness at particular times and in particular RF bands.

There are several ways that this too could be decolonized, including:

⁴ <https://www.wynnjacobsongalan.com/telescopes-on-stolen-land>

1. Recognition of the work and insights of Native astronomers and concepts of Indigenous astronomy.
2. Acknowledgement of tribal lands and ancestral lands, including resources such as spectrum.
3. Development of a more inclusive framework to consider and evaluate the impact of DSS on NRDZ testing sites, including obligations for government entities and scientific institutions to recognize Native Nations' rights in radio quiet zones and radio dynamic zones (RDZ).
4. Research and understand the societal, environmental, cultural, and economic impacts of the ngVLA on Native Nations, and follow proper procedures of consultation, consent, and inclusion of Native Nations and tribal citizens in the planning and implementation of the ngVLA.

What might this look like? In the context of dynamic spectrum sharing, DSS, arrangements that involve radio astronomy, Native Nations can be included as primary or secondary users in any arrangement. Coordination would occur with Native Nations, including sharing spectrum where possible.

The consequences could be profound. Imagine a world where Native Nations are involved in a spectrum commons, and where technology is used to give Indigenous peoples greater access to spectrum. Where that spectrum is valuable, it could be set aside for use by Native Nations, where tribes would hold the rights to their spectrum and have the ability to auction it to collect revenue, if desired.

Future Spectrum on Tribal Lands

What might the future of spectrum management on tribal lands look like? One possibility is to begin to develop capacity in tribal governments and institutions to manage spectrum, moving toward tribal spectrum sovereignty. The ideas of robust “tribal FCCs” could become a reality, especially on some of the larger reservations. Another possibility is to institutionalize thinking about greater spectrum access on tribal lands in the current spectrum management regime, largely on the federal side. The latter describes a minimal approach to recognition of tribal sovereignty, exemplified in policies like the Rural Tribal Priority Window. In this greater access approach, Native Nations could be considered secondary users in any sharing arrangement.

The more extensive approach is to recognize the inherent sovereignty of Native Nations. This would entail recognizing Native Nations as the incumbents, who are also in control of

the revenue from sharing arrangements when those arrangements involve spectrum on tribal lands.

Discussion and Conclusion

We have emphasized the utmost importance of spectrum sovereignty for Native Nations. Before the historical backdrop of federal Indian law and assumed supremacy over the Indigenous peoples of present-day America, it is easy to see how and why Native Nations have so little access to spectrum today. A trail of broken treaties, broken promises, and centuries of misguided federal policy has led us to this place and time where Native Nations are not benefiting from one of the most valuable natural resources known to humans: spectrum. With greater understanding and cooperation now than in the past, there are infinite opportunities to prioritize the needs of Indigenous governments and citizens in the fields of radio astronomy and spectrum governance.

Spectrum sharing sees spectrum as a finite, valuable resource and emphasizes that progress is a joint endeavor of government entities, industry representatives, and academic researchers. It is also an area where much more can be done to recognize the sovereignty and autonomy of Native Nations. It's not too late to recognize the needs and authority of Native Nations to manage, access, and benefit from spectrum on their lands. In the context of spectrum sharing, this means considering tribal governments as the incumbents, and not as a potential secondary user of spectrum. And it means recognizing that Native Nations and Indigenous peoples have realized very little from spectrum auctions and allocations, and hence equity considerations suggest the importance of a much more dramatic increase in spectrum access on tribal lands, revenue paid to respective Native Nations, and the inclusion of Indigenous brilliance in radio astronomy and spectrum governance.

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