Radio Dynamic Zones: Motivations, Challenges, and Opportunities to Catalyze Spectrum Coexistence

Mariya Zheleva, Christopher R. Anderson, Mustafa Aksoy, Joel T. Johnson, Habib Affinnih, and Christopher G. DePree

The authors discuss Radio Dynamic Zones as experimental platforms for large-scale research on spectrum coexistence of disparate stakeholders.

Abstract

The wireless spectrum is a natural resource upon which we all depend in more ways than we realize. While our personal and professional lives thrive on mobile broadband, a plethora of other applications, such as weather forecasting, climate science, astronomy, space exploration, and civil/military navigation also critically depend on the radio spectrum. Although these technologies are vastly different, they all share a common need for more spectrum and increasingly converge to the same bands. Currently, technological and policy frameworks are insufficient to facilitate the required mutual trust across distinct applications, and ensure their protection and harmonious coexistence. This article discusses Radio Dynamic Zones (RDZ) as experimental platforms for large-scale research on spectrum coexistence of disparate stakeholders. We consider three representative stakeholder technologies that have experienced exponential growth in spectrum needs and capabilities: consumer broadband, microwave remote sensing, and radio astronomy. We detail emerging coexistence issues across these stakeholders that can inform the design of RDZs. We then conceptualize an RDZ architecture and desired features and discuss grand research challenges towards their realization.

Introduction

The wireless spectrum is a finite natural resource that supports a plethora of applications vital to the well-being of humanity. Earth Exploration Satellite Service (EESS) provides weather prediction, advance warning for significant weather anomalies and helps us track climate change [1]. Radio astronomy (RA) uses spectrum to observe celestial phenomena and to explore the dawn of the universe [2]. Wireless broadcasting and communications have revolutionized our lives and economy by keeping us safe, informed and connected [3, 4]. These technologies are vastly different in terms of sensitivity levels, interference tolerance, and space, time and frequency usage patterns; yet as they evolve they increasingly converge towards many of the same frequency bands. Figure 1 presents a summary of spectrum capabilities and allocations across three representative stakeholder technologies most impacted by congestion: radio astronomy, remote sensing and consumer broadband (including mobile cellular and Low Earth Orbit satellite megaconstellations).[1] Light blue and green indicate capabilities for radio astronomy and remote sensing. Dark-blue presents primary spectrum allocations for radio astronomy. Darker green presents primary/secondary allocations for remote sensing. All consumer broadband ranges indicate allocations.

While the three technologies used mostly disjoint sets of frequencies in the beginning of the century, spectrum conflicts have grown in the 2020s and will continue to accelerate in the future. These conflicts are in part a result of the dramatic improvement in hardware and software technologies that have reduced the costs to access higher frequencies and use increased bandwidths. As a result, all stakeholders experience a rapid growth in technological capabilities, however, for some (e.g. RA and EESS) this has not resulted in new exclusive spectrum allocations. While the societal benefits from each of these disciplines are indisputable, measuring the importance of outcomes across stakeholders in order to determine spectrum allocations is often an exercise in comparing apples to oranges. Commercial technologies such as consumer broadband use economic gains or user coverage as a measure of their value. Accurate weather forecasting and climatology are indispensable to modern life, but characterizing their monetary value to justify new spectrum allocations is more challenging. For other stakeholders such as defense and scientific applications, economic value metrics may not directly apply, and may even be contrary to system requirements. The increase in demand for overlapping frequency bands by all of these services is severely straining our current spectrum management approaches. Ensuring unfettered access to spectrum by current and future users requires novel coexistence strategies developed, tested, and validated at scale.

The state-of-the-art in at-scale experimentation employs Radio Quiet Zones (RQZ) [5] and dedicated Innovation Zones (IZ) [6, 7]. However,

[1] Data for mobile cellular network allocations up to 2020 was retrieved from FCC rule-making and auction archives. Data for 2030 was found based on the planned discussions for new International Mobile Telecommunication bands during the 2023 World Radio Communications conference. Data for radio astronomy up to 2030 was obtained by surveying current and projected capabilities of AUI instruments. Data for remote sensing was based on surveying the launch times and capabilities of several satellite-based instruments, and potential future capabilities.

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these cater to disjoint sets of stakeholders and require substantial paperwork and approvals for active experimentation. This limits our exploration of coexistence issues across vastly different technologies. In this article, we explore the concept of a Radio Dynamic Zone (RDZ) as regional-scale experimental testbeds that can enable spectrum research into — and provide real-world validation of — the coexistence of disparate active and passive technologies. We begin by providing examples of key spectrum challenges for active and scientific users and discuss several examples of spectrum sharing systems where the development was severely restricted due to the lack of at-scale data that could have been provided by an RDZ. We then introduce the concept of RDZs justified in light of the limitations of existing experimental capabilities. Finally, we detail key features of and challenges associated with the implementation of an RDZ. This article is a result from multiple stakeholder discussions under the National Radio Dynamic Zones Partnership.[2]

Motivating Case Studies

In wireless communications, the paradigm of Dynamic Spectrum Access (DSA) is becoming a cornerstone for broadband technologies [8]. DSA allows shared spectrum access between licensed and unlicensed users, and hinges on automated measurement in support of general spectrum awareness and transmitter tracking with high sensitivity and fine spatio-temporal resolution. Although a variety of DSA paradigms have been proposed or implemented [3, 9, 10], their adoption has been hindered by a lack of large-scale experimental validation. Further, existing spectrum allocation processes inhibit the deployment of next-generation communication systems and have failed to support the evolving needs of scientific measurements. As a result, true real-time bi-directional spectrum sharing is not currently implemented, despite its clear advantages. Unlocking the potential of spectrum sharing will require testbed capabilities that provide interference-free and interference-controlled wide-area experimentation. In what follows, we discuss two motivating case studies that highlight the need for wide-area experimental facilities.

The Citizens Broadband Radio Service

A first step in the commercialization of true autonomous spectrum management systems was the Citizens Broadband Radio Service (CBRS) in the U.S. [4]. CBRS was designed to allow commercial cellular deployments to share spectrum with Naval radars, and represents the state-of-the-art in measurement-driven spectrum coexistence. The development of CBRS, however, was severely constrained by the lack of a large-scale tesbed where propagation models, spectrum measurement devices, aggregate interference levels, and dynamic spectrum management techniques could be validated. As a result, rules developed for the CBRS ecosystem were based only on existing models, assumptions, and simulations, many of which date back to the 1960s [11]. These rules employed predictions from propagation models, deployment, and operation assumptions that were highly conservative, rather than data-driven approaches derived from a real-world test range.

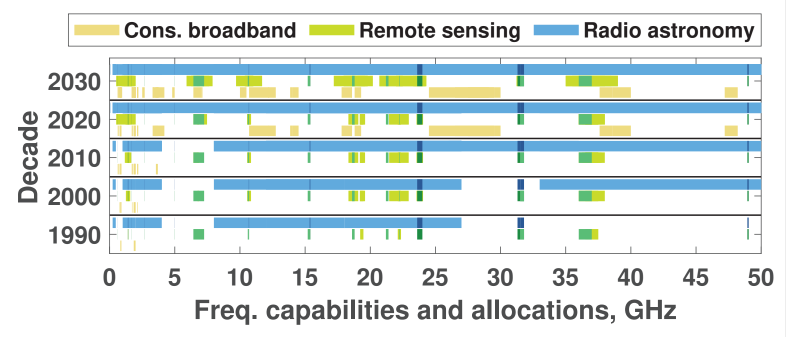

FIGURE 1. Spectrum capabilities and allocated bands across three stakeholders: remote sensing, consumer broadband (including mobile cellular and LEO satellite) and radio astronomy.

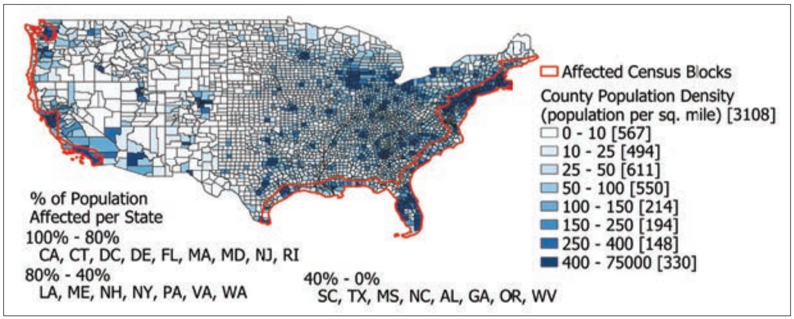

FIGURE 2. A map of CBRS exclusion zones overlaid on population density.

In particular, the CBRS rules specify the use of two propagation models for evaluating aggregate interference: the Irregular Terrain Model (ITM, also known as the Longley-Rice model) and the NTIA Extended Hata (eHata) Model. Although these models have a long and rich history of use in rulemaking, they have multiple significant limitations that result in an inefficient utilization of spectrum. In an effort to prevent interference to Naval radars, initial rules utilized these models to define a series of exclusion zones where CBRS systems would not be allowed to operate [11]. These exclusion zones, highlighted in red in Fig. 2, fall along the coasts of continental U.S. and in some cases extend hundreds of kilometers inland. Upon initial inspection, the vast majority of geographic area of the U.S. falls outside of the exclusion zones, leading one to believe that their impact on system deployment would be minimal. However, when overlaid with a population density map, nearly 40 percent of the U.S. population and 100 percent of the population in some states falls within exclusion zones. An RDZ could have facilitated more precise propagation models, validation of aggregate interference and spectrum management techniques through real-world experimental deployment.

Spectrum Use for Science and the Public Good

There are many spectrum stakeholders who, unlike profit- or defense-oriented technologies, use the radio spectrum for science and the public good. Examples include passive remote sensing for weather prediction (public good) and radio astronomy for scientific space exploration. Unlike active users, *passive scientific users* — particularly spectral line observers — are often not flexible in their spectrum use. For example, much of our understanding of the formation of stars

[2] For further details and documents visit https://www.cs.albany.edu/nrdz-ra .

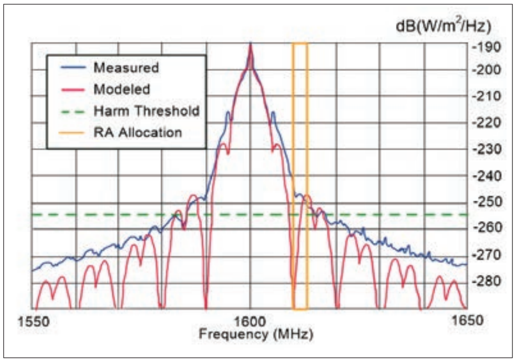

FIGURE 3. Modeled and measured spectrum of GLONASS transmissions showing its unintended impact on radio astronomy.

comes from the 1612.2 MHz line of the Hydroxyl (OH) radical transition. Measurements of these star emissions are performed by radio astronomy observatories with receiver sensitivity many orders of magnitude below those in commercial broadband. Spectrum conflicts are often a result of misunderstanding how susceptible observatories are to interference. For example, the GLONASS-L1 satellite navigation system adjacent to the OH band, has caused interference problems for observatories. Figure 3 [12] shows the modeled and measured GLONASS emissions, the location of the 1610.6-1613.8 MHz OH spectral line and the ITU-R 2403-0 harm threshold. The GLONASS signals exceeded the harm threshold, despite promised protections prior to the satellite launch. The resulting interference severely diminished observatories' ability to conduct scientific research in this band. The advent of ubiquitous broadband technologies, including satellite megaconstellations, further threatens radio observatories, which face challenges from aggregate interference from tens of thousands of satellites.

Passive microwave remote sensing of Earth's natural emissions also observes fixed spectral lines, which too are increasingly polluted by anthropogenic transmissions. For example, the 6-8 GHz and 1.41 GHz ranges are crucial for sensing sea surface temperature and soil moisture, which are vital for weather prediction and climate monitoring. Current spectrum allocations provide primary access in some bands, but only shared access in others. In the past, science goals could be achieved by operating in shared spectrum, but this approach is no longer possible as emitters have proliferated. The continuing growth in spectrum demand at higher shared-access frequencies (e.g. 23, 60 GHz, and beyond) further threatens remote measurements of Earth's natural thermal emissions.

These pressing spectrum conflicts motivate the development of experimental capabilities to facilitate the design, exploration and demonstration of novel coexistence methodologies. Despite this dire need, experimental testbeds are typically developed in isolation and usually in support of individual stakeholders, or multiple stakeholders of a certain type (e.g. two active users of the spectrum).

Overview of Radio Dynamic Zones

In this section, we conceptualize an RDZ's architecture as an interference-controlled large-scale testbed for dynamic access to spectrum across a wide range of zone users. Table 1 provides an overview of expected zone users and their desired resources and protections provided by the zone.

Radio Dynamic Zones

Advancing the state-of-the-art in spectrum sharing and demonstrating the viability of active-active and active-passive spectrum sharing approaches will require designated zones for wide-area, interference-controlled experimentation. An RDZ is envisioned as a regional-scale (geographic areas of 10's to 100's of square kilometers) experimental zone for coexistence research with disparate spectrum stakeholders. An RDZ, illustrated in Fig. 4, defines a geographical perimeter within which experimental transmitters and receivers can run controlled interference-free experimentation without inflicting harmful emissions on existing technologies — or other experiments — inside the zone. Further, experimental transmissions cannot depart the zone boundaries. Geographically-bounded regions like Radio Quiet Zones (RQZ) [5] protect sensitive instrumentation (e.g., radio astronomy telescopes) and may exist both inside and outside the zone. All RQZs are protected from RDZ interference; those inside the zone allow scientific instrumentation to opportunistically request quiet spectrum outside their dedi-

User Type	Desired Zone Capabilities	Desired Zone Protections	Examples
Managed experimenter Experimental technologies looking to evaluate feasibility through field trials.	• Dynamic resource allocation for interference controlled experimentation. • Access to share spectrum used by other zone users and stakeholders. • Large & diverse geographic areas to develop advanced models. • Access to large contiguous blocks of spectrum and protected bands.	• Protected from interference from incumbents and other experiments through time-frequency-space sharing. • Security and privacy to prevent reverse-engineering proprietary technology.	• WiFi-6, 5G, & 6G spectrum sharing. • Satellite & terrestrial spectrum sharing. • Measurement and modeling campaigns.
Managed incumbent Existing deployment inside the zone willing to cooperate with experiments.	• Access to spectrum near and within Radio Quiet Zones • Guaranteed quiet (interference-free) spectrum on demand. • Access to large contiguous blocks of spectrum and protected bands.	• Protected from interference from active incumbents and experiments. • Preserving licensed/protected bands unless actively shared.	• Radio Astronomy Observatory. • Commercial broadband & mobile wireless. • Active and passive satellite systems.
Unmanaged incumbent Existing technology inside the zone without experiment cooperation.	• Spectrum policy enforcement. • Access to zone spectrum analytics.	• Protected from interference from other zone experiments.	• Commercial broadband & mobile wireless. • Unlicensed devices. • LEO satellite mega-constellations.

TABLE 1. RDZ users and interactions with the zone.

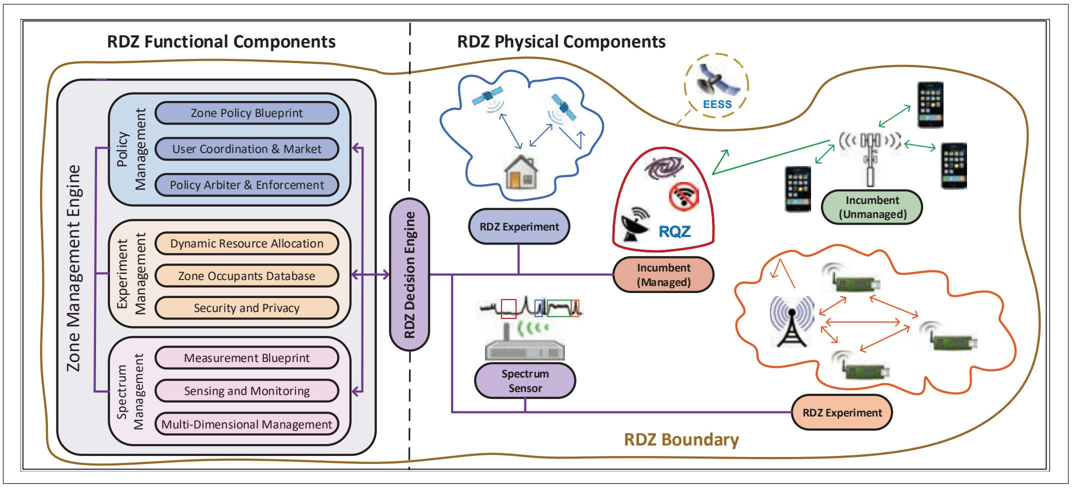

FIGURE 4. Overview of a Radio Dynamic Zone illustrating the key functional components in charge of managing the zone, active experimentation within the zone, potential incorporation of Radio Quiet Zones, and protection of incumbents and experimenters.

The Decision Engine will be responsible for managing the strength of all radio signals within the zone with respect to physical, spectral or temporal boundaries.

cated frequency bands. RDZ operation will be controlled by a *Decision Engine* that will rely on key inputs from three management subsystems: Policy, Experiment, and Spectrum. Each of these subsystems will provide the Decision Engine with information about:

1. The nature and types of experiments inside the zone
2. Spectrum policy rules, both specific to the zone as well national/regional rules
3. Protected incumbent users within the zone that may or may not be managed by the zone
4. Spectrum use and allocations that are informed by zone spectrum monitoring systems.

The Decision Engine will be responsible for managing the strength of all radio signals within the zone with respect to physical, spectral or temporal boundaries. Additionally, the Decision Engine must ensure equitable allocation of experiment resource requests, resolving disputes between experiments, and enforcement of zone policy. As a result, the *key feature* of an RDZ — as opposed to other forms of testbeds — is dynamic real-time coordination of all active and scientific experimental systems within the zone combined with interference protection to scientific users, sensitive instrumentation, and incumbent users within and outside the zone.

RDZs will be the first test sites to bring together disparate stakeholders, that traditionally have been isolated through a combination of spatial and frequency separation and have often had conflicting interests. This will facilitate a working understanding of stakeholder interactions, inform coexistence mechanisms and accelerate pathways towards practical deployments of spectrum-sharing technologies with pre-existing legacy systems. Additionally, it will facilitate the development of:

- Spectrum data collection platforms
- Cognizance algorithms that can glean actionable insights to support operational decisions
- Enhanced high-fidelity interference and propagation models.

Finally, RDZs can inform the design of next-generation RQZs for continued Earth and space exploration in the face of increasingly-complex and spectrum-hungry terrestrial wireless communications.

Current Approaches to Large-Scale Testing

In *wireless broadcast and communications*, novel research capabilities such as the Platforms for Advanced Wireless Research (PAWR) in the U.S. [6] bring promise for immersive experimentation in designated Innovation Zones. To date, these zones have been set up to facilitate active-active spectrum sharing experimentation in specifically designated bands. Experimentation outside of these bands requires prior coordination to avoid causing harmful interference to legacy technologies. Further, no zone has been setup to explore active-passive spectrum coexistence techniques with radio astronomy or remote sensing systems.

Currently, *radio astronomy observatories* are protected in space and (partially) in frequency inside RQZs. In general, fixed transmitters within the RQZ require extensive coordination with the zone administrator and special regulatory approval. In the frequency domain, radio telescopes have narrow-band interference protection around several spectral lines (e.g. Figure~\ref{fig:conf) through rules set up by the International Telecommunications Union (ITU). Spectrum sharing with these observatories thus requires time-consuming manual coordination and deconfliction in time, frequency, and geography. RQZs existing inside an RDZ could have more dynamic spectrum management, facilitating real-time bidirectional sharing between experiments and the observatory.

In *passive microwave remote sensing*, the pervasiveness of RFI has spurred research into technology to enable measurements to continue even in the presence of man-made interference [13, 14]. Because no current testbed can facilitate experimentation with either active or passive satellite systems, algorithm development has been constrained as researchers only have access to *in situ* recorded experimental data with limited knowledge of interfering signal properties. Advancing these techniques requires regional-scale experimental facilities to demonstrate and to develop the required sharing and interference mitigation algorithms.

RDZ Features and Grand Challenges

We now survey key RDZ features to serve the needs of a diverse group of stakeholders that

Functional component	Features	Capabilities
Policy management	Zone policy blueprint	• Flexible from "fully-open" to "fully licensed" • Distinct policies for in-zone vs out-zone user • Data accuracy and sharing interfaces for trustworthy analytics
	User coordination and market	• Two-sided market approach to trade resources for access • Incentive mechanisms for data sharing
	Policy arbiter and enforcement	• Accepting real-time interference reports from zone users and incumbents • Verifying interference reports with the spectrum and experiment management components • Dynamic, near-real time enforcement actions
Experiment management	Dynamic resource allocation	• Diverse active and passive users with managed and unmanaged devices • Sub-second allocations depending on the stakeholder
	Zone occupants database	• Data interface for entities with conflicting needs and diverse capabilities • Interface with regulatory bodies • Geolocation of zone users
	Security and privacy	• Secure transmission of experimenters' data through the zone network • Privacy-preserving geofencing of experiments
Spectrum management	Measurement blueprint	• Quality assurance for data coming from diverse and potentially unreliable sources • Trustworthy RFI benchmarks • Predictive measurement-based channel models
	Sensing and monitoring	• Sensing, data fusion and analytics scaled in DC-x100GHz target bands • Support of wide instantaneous bandwidths (x10GHz) • High sensitivity levels to cater to scientific users
	Multi-dimensional management	• Multi-dimensional resource allocation across time, frequency, space, angle and polarization • Fine multi-dimensional granularity informed by stakeholders' request/reaction times • Interference protection guarantees over all dimensions

TABLE 2. Summary of features and capabilities of an NRDZ.

span the range of terrestrial broadband, passive and scientific, earth sensing and remote satellite, to active satellite communications.

Overview of RDZ Features

Table 2 presents a summary of key RDZ features and capabilities, organized across the three subsystems of the zone. In *Policy Management* the *zone policy blueprint* will specify the licensing principles and chart stakeholder input data necessary for spectrum allocation decisions. Furthermore, it will provide a *user coordination and market* mechanism that ensures users are incentivized to share data and trade resources (e.g., access to specific frequency bands) for the purposes of experimentation. Finally, the Policy Management will also support a *policy arbiter and enforcement* ensuring that policies are fairly applied and that experiment violations are tracked and adjudicated. Some examples of experiment violations include causing harmful interference or eavesdropping on privacy-preserving geofenced experiments.

In *Experiment Management* the *dynamic resource allocation* feature carves out experiment resources for the diverse passive and active users of the zone. Resource allocation must be performed with sub-second granularity where needed, depending on stakeholders needs and capabilities. The decisions for resource allocation are based on user-supplied requests in the *zone occupants database*, which are validated with the zone and external policies and zone measurement blueprints. Finally, the *security and privacy* feature ensures that data is handled securely through the RDZ network and that where necessary, experiments are geofenced for privacy preservation.

In the *Spectrum Management* engine, the *measurement blueprint* specifies the schema and handles quality assurance for user-supplied data. The blueprint also maintains channel models and trustworthy radio frequency interference (RFI) benchmarks that aid in enforcement and resource allocation. The *sensing and monitoring* feature allows the zone to gather spectrum data to establish channel models and RFI benchmarks and to aid in conflict resolution. Unique to RDZ spectrum monitoring are the vast target band, large instantaneous bandwidths and sensitivity levels, jointly underpinned by the diverse active and passive stakeholders. Finally, the *multi-dimensional management* feature defines the degrees of freedom across which resources will be allocated, including time, frequency, space, angular orientation and polarization. Resource management must be performed with fine and flexible granularity and with interference protection guarantees across all degrees of freedom and stakeholders.

As depicted in Fig. 4 the three RDZ subsystems do not work independently. Indeed, the above discussed features support each other. For example, both the *policy arbiter and enforcement* and the *security and privacy* features subscribe with *sensing and monitoring* for objective enforcement and privacy-preserving geofensing of experiments. The *user coordination and market* subscribes with *mutli-dimensional management* and *dynamic resource allocation* to support fair resource allocation with stakeholders' needs in consideration. Finally, the *zone policy blueprint* and the *zone occupants database* subscribe with *sensing and monitoring* to ensure that data collection and analytics are trustworthy. The ultimate decision-making authority rests with the *zone decision engine* which must process information provided by its subsystems and allocate resources in real time.

Grand Challenges

Sub-second resource allocation. A core component of RDZ Experiment Management will be real-time dynamic spectrum allocation amongst diverse and geographically distributed users. Current administratively managed spectrum sharing (e.g. TVWS and CBRS) has response times on the order of minutes to hours, requires specialized hardware and software, and asserts active control over the devices being managed [4]. To be effective, an RDZ must support both managed and unmanaged devices, operate with sub-second response times, and ensure spectral and location privacy. It must also predict and manage the aggregate interference across active-active and active-passive use cases.

Sensing and monitoring. Depending on the stakeholder, experiments may take place anywhere between DC and sub-THz (or true THz) frequencies. Thus, sensing and spectrum characterization must support this large band. Furthermore, emerging active and passive technologies will work with instantaneous bandwidths in the order of ×100MHz (5G/6G) to ×10GHz (ngVLA observatory and THz communication systems). As a result, sensors' instantaneous bandwidths and spectrum characterization algorithms must support measurement and analytics of very large volumes of data capturing a variety of transmitters including wideband and narrowband, fleeting, terrestrial and airborne. RFI hunting must also be incorporated in analytics. The collected data and analytical capabilities should be open and available to everyone to facilitate trust across disparate communities, and should provide mechanisms for RDZ users to interact with the data. Finally, scientific and commercial stakeholders have vastly different sensitivity levels; sensing must cater to such high sensitivity and wide dynamic range.

Trust, security and privacy. RDZs are envisioned to bring diverse spectrum stakeholders together spanning from scientific to commercial and military technologies and from academia to the industry. Some of these stakeholders have traditionally had conflicting spectrum needs resulting in various issues of trust. RDZs must include by design trust-building and privacy-preserving capabilities to ensure diverse stakeholder cooperation towards improved access. To this end, RDZs need to include equal access capabilities, trustworthy data collection and modeling, and open interfaces to ensure transparency.

Examples of RDZ Experiments

In this section we discuss three important use cases of spectrum sharing architectures that currently present fundamental stumbling blocks towards harmonious coexistence. Experiments informed by these use cases can ground RDZ design in specific goals and demonstrate RDZs' utility.

Interference Characterization and Resolution

Over the past decade, a number of communication systems have been deployed that either share spectrum with incumbents, or operate in previously fallow spectrum adjacent to incumbents. Examples discussed at length in the literature include the aforementioned CBRS, C-Band 5G and Radar altimeters, WiFi dynamic frequency selection, WiFi 6 and 6 GHz fixed microwave links, and 5G next to GPS bands. In each of these cases, incumbents have vociferously complained about the potential harm of devastating levels of aggregate interference and have urged regulators to perform comprehensive testing prior to granting approvals. As a regional-scale testbed, an RDZ provides a number of features for controlled evaluation of RFI from large system deployments. The Zone Occupants Database and Multi-Dimensional Management features would manage a large number of geographically dispersed experimental transmitters and ensure interference protection to other zone users. Moreover, data shared by these experiments through the User Coordination and Market, as well as the Sensing and Monitoring features could be used to develop and refine existing models for aggregate interference, potentially enabling future regulatory action to proceed on a faster timescale and with less controversy. The large geographic area and regional-scale nature of the RDZ would enable extensive measurement campaigns and produce a new generation of propagation and interference models with improved accuracy and greater fidelity. Finally, the at-scale interference measurements would provide data-driven evidence to the susceptibility of legacy systems to interference from new spectrum-sharing technologies.

Dynamic Frequency Sharing with Radio Telescopes

In radio astronomy, coordinated spectrum sharing between passive and active users is a key experimental use case for an RDZ, and highly desireable to avoid a repeat of issues like the GLONASS problem. Such an experiment would require mutual spectrum awareness and coordination from both the observatory and the transmitter, which could be managed effectively by the User Coordination and Market and Dynamic Resource Allocation features.

This experiment could be run in a number of ways:

1. Radio telescope receivers and active transmitters within some appropriate radius could be coordinated across an entire bandwidth at an agreed upon timescale, with transmitters and receivers operating orthogonally in time
2. Radio telescope receivers and satellite transmitters could operate continuously in time, but would intersperse receiving and transmitting frequencies.

Either of these scenarios could make line-of-sight active transmitters "invisible" to radio telescopes, at a cost of either reduced observing time or reduced bandwidth (both of which reduce sensitivity). The Sensing and Monitoring feature would ensure that radio telescopes within the zone could both perform these experiments and operate free from RFI.

Spectrum Sharing with Passive Remote Sensing

Opportunities for shared spectrum access between active users and passive Earth sensing applications requires large-scale coordination provided by an RDZ. Earth observing microwave radiometers (part of the EESS service shown in Fig. 4) do not operate at 100 percent duty cycle at a given location due to their typical scanning of Earth's surface as a function of time, as well as

In radio astronomy, coordinated spectrum sharing between passive and active users is a key experimental use case for an RDZ, and highly desireable to avoid a repeat of issues like the GLONASS problem.

their periodic observations of internal or external calibration targets. Such systems are nominally outside the terrestrial bounds of the RDZ, and would only request access to spectrum to observe Earth's natural thermal emissions on an infrequent basis. Utilization of the User Coordination and Market as well as the Dynamic Resource Allocation features provides multiple opportunities for coordinated spectrum sharing in time with other users. Furthermore, radiometer measurement frequencies may be adjusted based on real-time spectrum availability as radiometers maintain their sensitivity to some geophysical parameters across a wide bandwidth. For example, NASA's L-band soil-moisture measuring SMAP radiometer antenna conically scans the Earth's surface. Its operation frequency, 1400–1424 MHz, on the other hand is bounded by ITU frequency allocations although sensitivity to soil moisture does not vary significantly at adjacent frequencies. Use of the Zone Policy Blueprint and Multi-Dimensional Management features could enable the development and demonstration of coordination paradigms with ground-, air- and/or space-borne microwave radiometers like SMAP that could subsequently be implemented in future radiometry missions.

Conclusion and Next Steps

The wireless spectrum is a precious natural resource. Maximizing the utility of this resource hinges on a continued conversation across stakeholders to conceptualize emerging coexistence issues, determine their degrees of freedom and ranges of operation, and discern how these factors challenge and inform the development of future systems. RDZs as regional-scale test zones are an enabling technology that will preserve spectrum access for all current and future users. Currently, conversations are centered around spectrum access as a binary: have and have-not. RDZs will result in a shift towards access that meets user requirements while promoting efficient sharing and use. This "good neighbor" approach requires understanding and mutual awareness of spectrum use and the associated societal benefits across many applications. To facilitate tangible progress towards the realization of RDZs, the community should identify a pilot area where interested stakeholders currently exist and can begin implementing the features and functional components of the zone. Finally, RDZ efforts should also promote the establishment of functional relationships between commercial entities and academic/scientific stakeholders to ensure maximal relevance of the tackled coexistence issues.

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