Unassigned Spectrum:

An Institutional Analysis of Radio Spectrum Management

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Abstract: Spectrum management is typically analyzed by comparing licensed from unlicensed regimes. The former is typically assumed to be a market regime and the latter analyzed through a lens of commons governance. We introduce the idea of unassigned spectrum as a general category of spectrum management that nests within it both licensed and unlicensed uses. The primary shared characteristic of unassigned spectrum is that a formal regulatory authority does not grant exclusive rights to users within a specific electrospace. We illustrate through case studies that spectrum management with unassigned spectrum may not require the establishment and enforcement of rights within a particular frequency/time/location and that governing unassigned spectrum may involve non-market approaches to tackling resource congestion. Through case analyses, we suggest a way to analyze spectrum management that goes beyond the licensed-or-unlicensed spectrum dichotomy. From a policy perspective, we argue that unassigned spectrum may contribute to more effective spectrum policies that address the diverse needs of users. We outline a strategy to differentiate spectrum allocation from assignment, discuss how several well-known spectrum bands can be interpreted as unassigned spectrum, and conclude with a preliminary discussion of implications for policy.

1 Introduction

Spectrum management refers to organizing the uses and users of electromagnetic spectrum with the intent of maximizing the social benefit from spectrum use. Radio Frequency (RF) spectrum is a natural resource that, unlike most other natural resources (like water, oil, or minerals), is intangible and is defined by governments with reference to wireless technologies and their capabilities and the use of the RF.[1] Like most other natural resources that are subject to rival

[1] That is, unlike water, oil, or minerals that exist as tangible resources irrespective of how they are used, radio frequency spectrum is an artefact that is defined in terms of how it is or may be used and the propagation characteristics of RF uses. The electrospace characterization of spectrum characterizes RF in terms of the frequency, time, direction of propagation, geo-location, and other attributes (Matheson & Morris, 2012). The ability to differentiate uses of the RF along any of these dimensions is limited by the state of receiver technology, which may change over time, with resulting implications for how spectrum resources should be managed.

consumption (or use), joint consumption of RF is limited by interference[2] even though spectrum is not technically used up.

Legacy spectrum management models focused on dividing the RF spectrum by *frequency bands* because the propagation physics, bandwidth, and hence wireless technologies, vary significantly as one changes frequency. The two most common and often discussed models for managing non-government access to spectrum relied on one of two dichotomous methods: licensed and unlicensed spectrum. The former has been associated with market-based spectrum management because it relies on the exclusive assignment of spectrum rights to a single entity (most often a commercial entity with a for-profit business model) that is then expected to manage the spectrum efficiently. The latter model has often been analyzed through the lens of commons governance, wherein, no single user has exclusive usage rights to the spectrum and governance relies on the norms and rules that specify how unlicensed users may access the spectrum. In the US and most parts of the world, most of the spectrum used by Mobile Network Operators (MNOs) is licensed spectrum. Those MNOs hold long-term exclusive licenses to manage and use specific frequency assignments in specific locations, with assurance of property right protection against interference from non-affiliated users. The most popular unlicensed bands are the ISM bands used by Wi-Fi radios (and others like Bluetooth, cordless phones). Use of those bands is shared by all compliant radio devices, with no user having a claim for interference protection from any other compliant user.

In practice, both the licensed and unlicensed models are subject to significant variations across countries, radio-frequency bands, and local contexts. Both models support a wide array of strategies for sharing spectrum resources among multiple users to reconcile the conflicting demands of users for scarce spectrum resources (2020). As noted above, spectrum is an atypical type of resource. Another way in which it is atypical from many other types of natural resources (such as timber or minerals) is that it is renewable (like bandwidth). That is, spectrum resources that are not used cannot be recovered, and so, the challenge is to enable as many valuable uses (to be able to access or share the spectrum) as possible without those uses causing destructive interference in a specific time window and geographical area. Achieving this dynamic sharing goal has different incentive and performance characteristics under the licensed and unlicensed models, with complex implications for technical and economic performance. Disentangling these different effects in the quest of better models for managing spectrum resources is a key motivation for spectrum management researchers. Too much of the policy debates over spectrum management reform have focused on the dichotomous models of exclusive licensed (favored by MNOs) versus unlicensed (favored by many edge providers of wireless content, devices, and applications) and which offers the greater value to society in terms of economic welfare and equity. Too often those debates fail to adequately appreciate the ways in which these models complement each other in practice and deviate from their stereotypical characterizations.[3]

[2] Interference itself depends on transmit and received powers, locations of devices, and radio propagation in a given environment.

[3] For example, MNO subscribers regularly use WiFi on their mobile devices and MNOs make ample use of both cellular and WiFi spectrum to address coverage and capacity gaps. MNOs offload traffic to WiFi to reduce congestion of their licensed frequency and cable-based MVNOs offload traffic to MNOs to fill coverage gaps not met by their deployed WiFi networks. Additionally, the stereotypical characterizations of licensed v. unlicensed models characterize licensed users as having exclusive interference protection and unlicensed users as having no such protection under the law. That is incorrect on both counts. Licensed users typically are encumbered with easements

In this paper we propose a new framework for spectrum management that side-steps the legacy analysis of licensed v. unlicensed spectrum, focusing instead on the alternative concept of *unassigned spectrum*. Unassigned spectrum refers to allocated frequency bands where users have not been granted exclusive rights within a particular electrospace (Matheson and Morris 2012). Most significantly, unassigned spectrum nests both licensed and unlicensed uses under a general policy framework: nothing prohibits stakeholders from developing their own self-enforcing licensing systems, invoking government regulatory interventions when needed. The shared feature within this framework is that eligible users are not assigned specific electrospace allocations. We argue that this feature requires governance in a way that extends beyond the conventional discussion of unlicensed regimes to also include formal governance practices conventionally analyzed in licensed-spectrum contexts.

This unassigned spectrum approach presents a middle-ground between unlicensed and licensed users with respect to the definition of property rights over usage of the spectrum and rights to exclude other users, which offers a key component for how non-interfering co-existence of shared access may be managed. Although exhaustive assignment of spectrum license rights may make sense in many contexts and a model approximating that goal has proved attractive for MNOs and other wide-area networking contexts, the cost of defining and enforcing property-rights boundaries may exceed social benefits in many situations.[4] Alternatively, an unlicensed regime that does not provide mechanisms for mitigating the threat of overuse from a Tragedy of the Commons, poses another source of problem. The unassigned model elects to avoid an exhaustive assignment of property rights but addresses the congestion-management challenge via recourse to non-market spectrum-sharing practices.

In the following section, we explain precisely what we mean by "unassigned spectrum." We begin this paper by distinguishing spectrum allocation from spectrum assignment and proceed brief descriptions of some well-known examples of unassigned spectrum. Then in Section 3, we consider five cases of unassigned spectrum: unlicensed bands (including WiFi), amateur radio, citizen's band (CB) radio, radio astronomy, and satellite communications. The following section discusses the similarities and differences of these cases. In the conclusion, we offer some suggestions for the policymaking community.

2 Defining Unassigned Spectrum

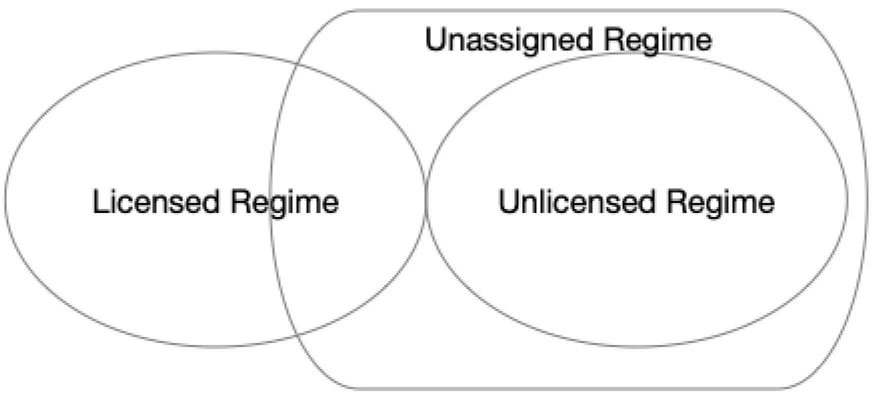
Unassigned spectrum refers to spectrum that has been allocated for a use, but where excludable usage rights have not been granted (assigned) to a specific user for a particular block of

granting use to unaffiliated third-parties (e.g., UWB devices), and unlicensed users may make interference claims against non-compliant devices. Both regimes are property rights regimes, just with different rights and obligations, norms and practices, and institutional protections applicable to each – and within each regime, there is significant variation across licensees and bands.

[4] As Demsetz (1967) argued, exhaustive assignment of property rights ensures that the rights holder has strong incentives to internalize all economic effects of using the spectrum efficiently, and hence is more likely to do so. A problem is that designing, allocating and *enforcing* those rights can be quite costly, including ensuring that those rights to not give rise to market-power threats to competition or innovation.

electrospace (i.e., time/space/frequency tuple). Excludable rights over resources grant owners discretionary authority over *excluding others* from using the resource. Unassigned spectrum therefore captures a broad class of governance structures in which spectrum is allocated by a formal authority to a potentially broad set of stakeholders, but significant freedom is granted to stakeholders in allowing them to shape their own specific spectrum assignment or use protocols. Moreover, those stakeholders may not be specifically identified, as in the case of licensed spectrum where the license holder is a specific entity. However, it does include unlicensed spectrum as well as several other regulatory models that we discuss further herein. Figure 1 captures the essential features of unassigned spectrum.

Figure 1. Unassigned Spectrum



We use broadcasting as an example of excludable rights through licensure. It is the approach that dominates much of the thinking and literature in spectrum management. Briefly, in broadcasting, spectrum is allocated to AM radio, FM radio and Television at the ITU. The FCC affirmed this allocation in the US. The FCC then developed procedures (in this case, beauty contests) for assigning transmission rights to particular users at particular frequencies in particular locations (see generally Hazlett (2017) for analysis of changes in FCC rules governing assignment). For some licenses, the permissible times of day may also be included.

A similar approach is taken for mobile communication systems, except that licenses are not granted for a single transmitter, but for a region (such as a set of metropolitan areas or rural areas or both). This liberalization allows the license holder to construct systems without having to seek authorization for each transmitter (base station, or cell). This, in turn, allows carriers to manage co- and adjacent channel interference arising inside their system directly.

In licensed spectrum, license holders have an exclusive right for intentional emissions in the electrospace as defined by the license.[5] As noted earlier, this singular assignment concentrates control of how the spectrum is managed and the rights to appropriate the value that efficient use enables on the licensee. Exclusive use provides strong private incentives to use the resource efficiently, which has long been touted as a significant benefit of exhaustive assignment of property rights to private interests. Since license holders have a high level of control, they can engineer systems to be very efficient, exploiting expert knowledge that is typically not available

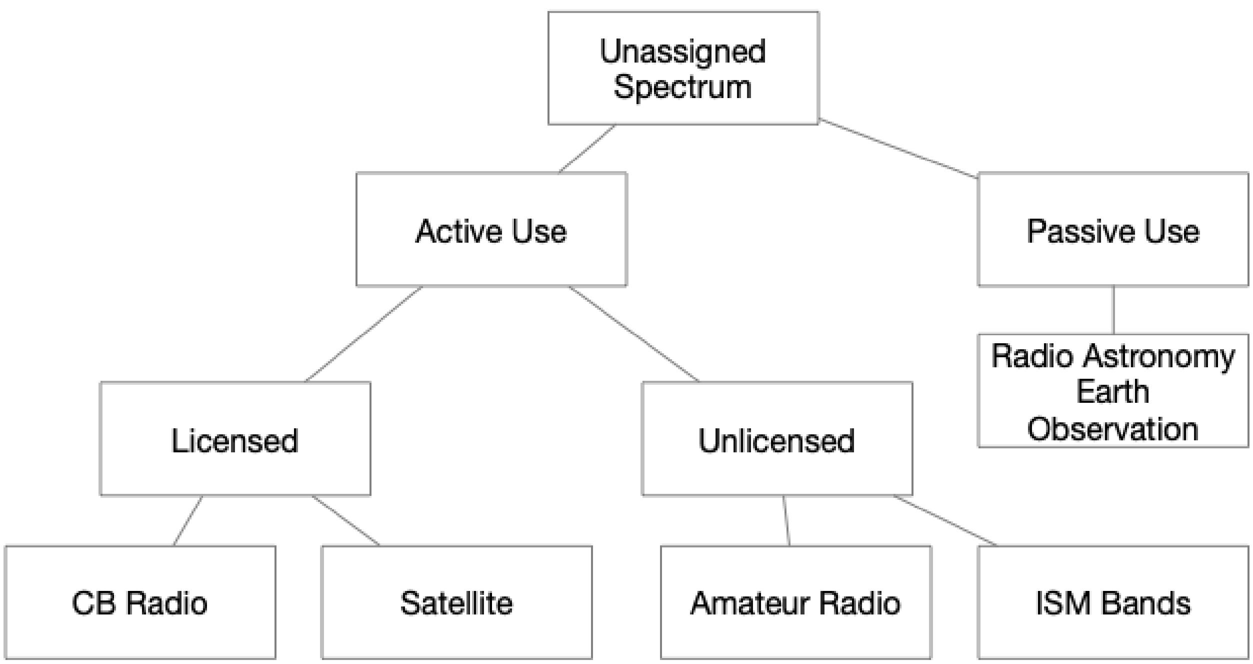
[5] Spurious transmissions from electrical and electronic devices are often excepted from this.

to regulatory authorities, while avoiding the inherent inefficiencies of bureaucratic governance. The Darwinian "survival-of-the-fittest" process of market-based competition among licensees (if competitive forces are sufficiently robust) helps ensure that license holders are pushed to operate at the efficient frontier, minimizing costs and maximizing total welfare. Moreover, if and when interference arises, the exclusion rights granted to license holders provides them with a legal capability to pursue enforcement actions against the offending transmitter. This applies as well to spectrum sharing arrangements, where either the primary or the secondary user may transmit and have right of action in the event of "harmful interference". Temporary licenses (Bustamante et al. 2020) are also considered assigned spectrum in our definition.

3 Case studies

In this section, we briefly describe some cases that are useful in framing the analysis below. The case studies are depicted in Figure 2, which highlights that unassigned spectrum includes cases of both licensed and unlicensed use. We use these cases to explore the factors that favor unassigned spectrum and the various approaches to its governance. These cases are all examples of applications where a frequency allocation has been made without assignment to users. Thus, all users of the band/application must share the allocated frequency without exclusive rights in space or time. When electrospace must be shared, the possibility of congestion (or interference) arises, so the allocation exhibits characteristics of a commons. In her body of work, Ostrom (2015) found that users of resources often coordinate themselves without relying primarily on a centralized authority to enforce rules, thereby avoiding overuse of resources. Ostrom explored the characteristics of communities, including institutions governing relations among community members, that contribute to more effective management of shared resources.

Figure 2. Cases of Unassigned Spectrum



In this context *governance* refers to the formal and informal institutions that emerge to sustainably manage a resource. Informal governance institutions pertain to unwritten norms, practices, and social arrangements that emerge spontaneously within a community to facilitate collective decision-making and the management of common-pool resources. Contrasting formal governance institutions, which possess explicit rules and hierarchical structures, informal governance institutions operate on a more decentralized and flexible basis, relying on shared understandings and social interactions. Thus, we can characterize formal governance institutions by their explicit, codified rules and regulations that outline the rights, responsibilities, and obligations of individuals or groups involved in the management of shared resources. These institutions typically operate within a broader legal framework and possess authoritative decision-making powers, often delegated by the state or other governing authorities.

3.1 Unlicensed Spectrum

The FCC has designated bands on which users may transmit without first obtaining a license. These bands have been adopted by the spectrum management authorities in many countries around the world, have limited transmit power and sometimes other transmission characteristics (by regulation, for instance by the FCC). Such limitations are enforced through *equipment certification* by the regulatory bodies, but unlicensed spectrum bands have been used for a great variety of purposes, from cordless phones to garage door openers to wireless computer networking and more. Because unlicensed bands have the characteristics of an open access commons, regulators may choose to establish technical parameters, such as maximum transmit power, and etiquette rules to reduce the effect of contention for the use of this spectrum.

Some important aspects of unlicensed spectrum are that each user has equal rights to transmit in a band, and that there are no formal actions that a user can take against another user in the event of harmful interference. Despite this, conflicts between co-located users still take place (Sandvig 2011). Similarly, conflicts between uses can occur, for example, when mobile carriers proposed using unlicensed bands for mobile services, a service that was initially called LTE-U, users of "traditional" unlicensed applications objected at the policy level (Krishnamurthy, Murtazashvili, and Weiss 2021). Additionally, other examples of coordination (e.g. in condominium associations where non-overlapping bands of WiFi may be coordinated) are found in (Weiss et al. 2015).

3.2 Amateur Radio

As in unlicensed spectrum, frequency bands are allocated to amateur radio (AR) without being assigned to any particular user. Unlike the unlicensed bands, users ("ham operators") must pass a licensing examination to transmit on these bands, and they must keep their license current.[6] In the US, there are three different tiers of this license, which offer ham operators progressively more transmission privileges. Unlike unlicensed users, amateur radio users are strictly prohibited from engaging in commercial uses of this spectrum. Like unlicensed use, no amateur operator has cause of action to mitigate interference. Amateurs may only refer complaints to the FCC for possible enforcement.

[6] 47 CFR 97

AR license requirements are not like licenses in other RF spectrum bands. It is more akin to a certification of competency, and so bears similarities to the equipment certification required to operate in ISM bands. Thus, AR licenses do not grant transferrable exclusive ownership rights (it cannot be leased, for example). As pointed out in (Bustamante et al. 2022), there are several license categories that confer different operating rights (e.g., privileges to operate in different spectrum bands and at different power levels). The ARRL's Volunteer Monitoring Program observes bands and notifies users if they operate outside of their license class; in fact, more than half of the VMP's reported actions are of this type[7]. Under a Memorandum of Understanding (MoU) with the FCC, these violations may be reported for further investigation.

As discussed in Bustamante et al. (2022), the amateur radio community has developed an elaborate polycentric system to govern the spectrum allocated to that purpose. As well, the rigor of the licensing process means that amateur radio behaves more as a private commons, where entry requires the acceptance of community rules (in the form of regulations) and extensive integration experiences are available through amateur radio clubs.

3.3 Citizen's Band

Since 1948, the FCC created opportunities for short, radio-based communications between individuals. It was intended to be distinct from Amateur Radio in that commercial messages (e.g., dispatch) were permitted and that little or no technical expertise was required to obtain a license. CB was intended for short messages, not long conversations. In fact, the original FCC rules put a 5 minute limit on conversation length (Scherrer 2000). It was not intended for data services, device to device services, or to replace telephone service. The Citizen's Band service was later expanded to include Family Radio Service (FRS) and General Mobile Radio Service (GMRS). Each of these services operates at different frequency bands and/or permitted power levels. Originally, licenses were required for users of CB but the licensing requirement was discontinued in 1983[8] (Holsendolph 1983). While this case should therefore consist of two sub cases, the license requirement was so light that it had little effect on user behavior, so we treat the case singularly.

The history of much of the licensed era of CB can be found in (Marvin and Schultze 1977; Scherrer 2000). This case concerns what was once designated as Class D and which operates in the 27 MHz band, which enabled the sale of much less costly transceivers. CB was intended for short voice messages, as might be needed for dispatch, emergency communications, etc.

Like amateur radio and unlicensed, no CB user is assigned a time/space/frequency block. Unlike amateur radio, CB users (in the licensed era) obtained their license by filling out a form (Hicks 1964); no examination was needed. This low barrier to use was intended to broaden the appeal of CB to encourage its adoption and use. But the consequence of this was that, unlike amateur radio, CB was effectively an open access commons. That said, some institutions emerged (Scherrer 2000). For example, REACT (Radio Emergency Associated Communications Teams) was formed in 1962 to successfully lobby for Channel 9 as a channel for emergency (roadside) assistance. REACT then coordinated as many as 800 local team to monitor the channel. This was necessary

[7] https://www.arrl.org/volunteer-monitor-program, retrieved 28 July 2023

[8] 47 CFR 95 for the general rules for PRS. Licenses were made optional by Congress in PL 97-259—SEPT. 13, 1982 (96 Stat. 1093). Today, licenses are required for GMRS radios only.

because the limited range of the CB meant that no national monitoring was possible. Eventually four national clubs emerged, even though the activities, which were mostly social, remained highly local (Scherrer 2000).

The CB boom during the 1970s and 1980s resulted in highly congested channels, similar to what one might expect in a commons with little governance (GAO 1975; Meltzer 1975). Indeed, the use of CB by truckers to circumvent the nationwide 55mph speed limit in the 1970s (Watts and Barton 2011) led to the CB boom. As noted, it is reasonable to conclude that the culture surrounding CB use was more anti-authoritarian than focused on maintaining a community resource through self-enforcement.

Even though CB has a limited reach due to limits on power, traditional allocation of exclusive rights is not a good fit for this application, in which users may be highly mobile (in the case of truckers, for example) and entry is prioritized. Furthermore, the low permitted power levels meant that the range of CB radios was very limited (about 15mi or 24km).

3.4 Radio Astronomy and Earth Observation

While radio astronomy and earth observation are distinct applications and uses, they share many common characteristics. So, for the purposes of this paper, we treat them together. Most important among them is that these applications do not control the transmitter, so the receivers for these services must be highly adaptable. As well, the frequency bands used by these applications are specific to the phenomena being observed/studied, so they cannot be relocated to an alternative band. It is possible that some terahertz frequency-based sensing applications of the future may also fall into this category.

These applications require a very low ambient electromagnetic noise level to function properly. Like the other services, though, radio astronomy is given an allocation; because it is a *passive* use, the traditional licensing approach, which is focused on regulating transmitters, does not fit the dominant regulatory model. Governance of these bands is largely focused on protecting the bands, which consists of maintaining the low noise environment as well as ensuring that the allocation is persistent.

As described in (M. B. Weiss et al. 2021), the primary governance institution in the US is the Committee on Radio Frequencies (CORF) of the National Academies of Science (NAS).[9] They work with the FCC, ITU and National Science Foundation (NSF) on matters related to passive spectrum, which includes protecting the spectrum from re-allocation and interference from other bands and applications. This also can provide a form for the passive radio use community to exchange ideas and experiences.

3.5 Satellite Systems

Since the dawn of the satellite era in the 1960s, spectrum has been allocated for communications satellites. These allocations include both uplinks (earth to satellite) and downlinks (satellite to earth). In recent years, systems such as OneWeb and Starlink have been proposed (and launched)

[9] https://www.nationalacademies.org/our-work/committee-on-radio-frequencies

to enable satellite-based Internet services, especially to rural areas. These systems share common spectrum for uplinks and downlinks, spectrum that has been allocated for satellite communications.

These systems though these systems must obtain an operating license, which includes a license to use the allocated bands, none of the systems has a particular assignment (Berry et al. 2022). Operating licenses are granted in successive "rounds," in which the new applicants are treated as a group. As discussed in Berry et al. (2022), the FCC is considering developing a system of priorities among the rounds.

Using an assigned spectrum model is challenging in this case for several reasons. First, a satellite is only over a certain geographical location for a short time, so geographically defined spectrum would be under-utilized. Second, satellites transition national borders, and countries may not have regimes in common.

As briefly alluded to in Berry et al. (2022), governance of the shared spectrum is fairly limited. In the US, the FCC has challenged LEO firms to coordinate among themselves, with the threat of a draconian sharing regime in the event of interference if they fail to do so. Right now, only Starlink and OneWeb have reached such an agreement; the details of this arrangement have not been disclosed.

3.6 Summary

In each of these cases of unassigned spectrum, the governance institutions are designed to balance access to a resource with an acceptable level of congestion and/or interference. Table 2 captures the core features of these systems. Congestion can result in interference, as, for example, when too many WiFi access points seek to operate in a small geographic area. But congestion may be desirable as well, for example, when radio amateurs are "DXing'" or CB users are trying to exchange information. Without some level of congestion, these uses would not be satisfactory. Interference is generally unwanted electromagnetic energy. Radio astronomers and passive spectrum users are especially sensitive to this unwanted energy because the phenomena they are studying produce very weak signals. This unwanted energy can be natural or man-made, and it is the man-made interference from other (active) bands that is a particular focus of the external policy advocacy of passive users.

Table 1. Features of Types of Unassigned Spectrum

Feature	Unlicensed	Amateur Radio	Citizen's Band (CB)	Radio Astronomy	Satellite Communication
Licensure	No license required	License required	No license required since 1984	No license required	Operating license required
Use	Diverse uses, such as for Wi-Fi, Bluetooth, cordless phones and baby monitors.	Non-commercial communication, such as for radio enthusiasts and experimenters.	Brief personal, and commercial communications, such as for dispatch and walkie-talkies.	Scientific research and telemetry applications	Commercial and government communications, such as for satellite communications and television
Challenges	Diverse uses, no entry control, weak use coordination	Compliance with FCC rules, protection of allocation	Mobility of users, Weak institutions, culture of rebellion	Interference from adjacent bands, protection of allocation	Competition between systems
Formal Governance	Spectrum etiquette (technical), Equipment certification (FCC)	FCC rules and enforcement	FCC rules and enforcement	CORF, FCC	FCC Satellite policy
Informal Governance	Tie to real estate rights, informal management, WiFi Alliance	ARRL, Local Clubs, Frequency coordination, recommended band plans	Local clubs, REACT, Orgs of verticals (e.g., farming, truckers)	Advisory	Bi-lateral agreements

Notably absent from this discussion is the multi-tiered Citizen's Broadband Radio Service (CBRS) approach to spectrum use. For this paper, we consider CBRS to be an approach to sharing that includes, in the General Authorized Access (GAA) mode, a mechanism that is has many resemblances to unassigned spectrum. GAA is different than the above models as its use requires the absence of incumbent and Priority Access License (PAL) users and is specified on a regional basis rather than nationwide. Thus, while it has similarities, there are also key differences, so we elected not to include CBRS as a case for this analysis.

4 Discussion

4.1 Framework

We analyze these cases through the lens of common pool resource governance. In that light, Elinor Ostrom argued that polycentric systems, which recognize a role for local autonomy that enables adjustments to facilitate experimentation, are especially significant for goods where access and consumption are rival to varying degrees. Studies have described telecommunications as polycentric. These polycentric features include leadership and innovation from the business sector (Sawhney 1993), non-traditional communications regulators in certain aspects of communication, including provision of rural broadband (Ali and Duemmel 2019), and collaborative, multi-stakeholder governance (Feijóo et al. 2020).

More formally, polycentric systems have the following features (Bustamante et al. 2022):

- Autonomy of local units: local units manage resources
- Multiple levels of rules: Formal and informal rules act at different scales
- Membership rules: Use is delimited in some way that defines who can use a resource
- Adaptability: Ability of users to respond to changing opportunities and conditions
- Nested Governance: Several levels of governance with different scope, different rules; delegation and recognition of authority
- Enforcement: Graduated sanctions, often with enforcement by multiple, nested organizations x

4.2 Analysis of the Cases

At the highest level, each of these cases share allocation without assignment. As we consider governance, consideration of commonality requires more nuance. For example, the governance needs of passive users are generally different than active users, though even in this case, protecting allocations is a common priority. Unlike passive users, the governance challenge of maximizing use of the spectrum means controlling overuse by an individual user. The governance systems of unlicensed, amateur radio and CB introduced a combination of human behavioral standards and technical rules to accomplish this goal.

Table 2. Polycentric Features of Unassigned Spectrum

	Unlicensed	**Amateur**	**CB**	**Passive**	**Satellite**
Local Autonomy	Spectrum etiquette may coordinate local use.	Local radio clubs offer guidance to local amateur communities on frequency use	Local radio clubs exist for social networking & to monitor channels for emergency comms	Local users work with spectrum neighbors	Bi-lateral agreements between operators
Multiple levels of rules	Overall operating rules established at the national level (FCC in the US)	Frequency coordination among repeaters occurs on a regional basis; ARRL coordinates on a national level; FCC has final authority	Overall operating rules established at the national level (FCC in the US); Coordination on channel uses;	Relevant rules are transmission masks of *other* bands that potentially generate, co-channel, adjacent channel, IM, etc. interference	Overall operating rules established at the national level (FCC in the US
Membership	Equipment ownership	Licensure	Pro-forma licensure/ Equipment ownership	Site acquisition and operation	Licensure
Nested Governance	None	Local Clubs; ARRL; FCC	National orgs; FCC	CORF; FCC	FCC

Enforcement	FCC equipment authorization	Volunteer Monitoring/ FCC Enforcement Bureau	FCC Enforcement Bureau	FCC Enforcement Bureau	FCC Enforcement Bureau

4.2.1 Similarities across the cases

First, a hallmark of *all* unassigned spectrum is the adaptability of this approach to novel uses and technologies. Second, the ultimate authority in enforcement is the FCC, either through its enforcement bureau or through equipment certification. Third, we note that all approaches have some kind of local governance, though there are significant variations in the strength of these institutions, the issues of importance and their constitution.

More generally, for each category of unassigned spectrum, the activities are regulated by the FCC, though regulation is incomplete. Membership rules operate to some extent, though licenses are not the only way that membership is defined, as some unassigned use does not require a license. In each category, there remains substantial opportunities for self-governance. In the unlicensed band, for example, coordination to allocate use of WiFi and cell networks is a key feature of governance (Sandvig 2004).

4.2.2 Differences among the cases

While there may be some commonalities among these cases, there are several notable differences among the cases as well. Most notable among these is that each serves a very different purpose, and each has a unique regulatory structure. The mechanisms through which users may participate in each case is also highly divergent, ranging from simple equipment ownership (in the case of unlicensed) to examination-based licensure (in the case of AR). Also, while all cases feature formal and informal governance, there is a substantial diversity in the nature and structure of the governance institutions.

We consider amateur radio as an example. The autonomy feature is present as amateur radio clubs are not subsidiaries of the AARL. Rather, these clubs have their own constitutions that establish their rules. There are multiple levels of rules governing Amateur radio, in particular formal and informal rules operating at different scales: Part 97 rules apply nationally, while club rules govern local amateur radio communities. Membership rules are defined through FCC licensing requirements, while club membership constitutes another layer of membership. One of the adaptability features includes the potential to change Part 97 rules through administrative processes, including updating these rules, as well as frequency coordinator response to new repeaters. Governance is nested in the following sense: IARU operates internationally; ARRL coordinated nationally; clubs operate locally; and local councils coordinate on an ad hoc basis. The self-governing features of enforcement include self-appointed “spectrum police” as well as the ARRL’s Volunteer Monitoring Program. Working rules include etiquette norms for use of AR bands by members of the club.

With respect to regulation, the most significant difference is whether licenses are required. Both amateur radio and satellite require licenses, while no license is required for unlicensed bands, CB, or radio astronomy. While this was not always the case for CB, the licensing process was very simple by design, consisting of filing a form with no required examination, that it was effectively license free. Today, only GPRS requires such a license.

This requires perhaps more coordination where licenses are not required, though in each case, we see that informal governance remains significant. Hence, the regulatory requirement of a license does not eliminate the need for governance, which is one of the reasons why the licensed-unlicensed continuum is insufficient. As discussed earlier, the usual perspective is that licensed spectrum addresses governance through licensing, though in the cases of unassigned spectrum, it remains a significant consideration.

Uses also differ across the cases. The cases considered include uses such as WiFi, scientific research, and commercial use, as well as uses by public and private entities. The discussion of the diversity of uses under the heading of unassigned spectrum further justifies consideration of unassigned spectrum as an analytical category: a great many uses are captured under this framework.

There are also significant differences in formal and informal governance. In each case, the FCC is a common regulatory body in the US, as the FCC has authority over all use of non-governmental spectrum in the United States. Still, there remains a diversity of informal rules and norms that govern use in each of the cases. AR operates through a system of clubs, while in the other cases, there are a diversity of substantive norms governing appropriate use. The substance of the norms differ, though they share that they are informal.

4.3 Social Consequences of Unassigned Spectrum

4.3.1 New/unintended uses

One of the consequences of unassigned spectrum is that it may be more appropriate for new or unintended uses. New and unintended uses suggest greater uncertainty regarding the way to design rules to ensure socially beneficial use of spectrum. This includes uncertainty about the manner of assignment of spectrum to increase changes for socially beneficial use. Though unassigned spectrum involves some degree of centralized governance, and may involve licensing, flexibility to assign spectrum is a feature of such unassigned spectrum management.

Unassigned spectrum may also encourage new uses. The nature of unassigned spectrum is that it is less constraining in determining ex ante the appropriate uses of spectrum. In this sense, it may encourage new or unintended uses.

4.3.2 Innovation

Another rationale for unassigned spectrum is to encourage innovation. One of the challenges with licenses is that they create persistence in spectrum: innovation may be more challenging because incumbents have rights. This has sometimes been describes as the monopoly problem with assignment of property rights (Milgrom, Weyl, and Zhang 2017; Posner and Weyl 2017). Some unassigned bands are licensed, but there is flexibility in assignment. Hence, de facto assignment may change more rapidly than in situations with licenses that create monopoly power.

4.3.3 Value

Unassigned spectrum generates value, though this may be more challenging to define. Consider two of the cases: AR and satellites. AR can be described as open innovation, in that the contribution of the use of a public band generates benefits, but those are diffusely defined. Hence, an unassigned band may be appropriate to manage those values. For satellites, one of the challenges is that the social benefits of scientific uses may be more challenging to quantify than the benefits of licensing. For example, the benefits of exclusive use can be measured by the size of the private telecommunications market or the extent to which those businesses provide broadband coverage (Hazlett and Muñoz 2009b; 2009a).

5 Conclusions

The conventional approach to spectrum management considers the opportunities and challenges with spectrum management in a dichotomous manner: Unlicensed activity requiring full self-governance and licensed activity governed purely by market mechanisms. In reality, a vast array of governance options exist and are observed within the spectrum industry and a richer policy framework can allow policy makers to consider how formal regulatory actions interact with endogenously generated self-governance practices.

Our analysis suggests that unassigned spectrum can be useful as a general category of rules to govern spectrum that complements the licensed-unlicensed typology, and that the presence or absence of a license does not eliminate the requirement of governance. We also see unassigned spectrum as generating certain benefits, including encouraging new uses, innovation, and that such systems are appropriate when the value of the activity may be challenging to define.

The broader point we wish to make is that Ostrom's contribution is valuable precisely because it is the more general case that in its extremes may take you to either exclusive licensed or unlicensed. Ostrom’s approach recognizes that exclusivity/rivalry are always imperfect in real world. Ostrom does NOT say open commons is right model, but rather if one starts with a perspective that leaves assignment (exclusive ownership, in extreme model) open for consideration, examining why that is or is not the right model and what other mechanisms and instruments are available to allow for more adaptive, flexible "enforcement" (broadly interpreted to include certainly all formal, legislative, regulatory mechanisms as well as norms and informal mechanisms which vary widely across our cases) may offer a better model. Indeed, the exclusive licensed ideal of full transfer of property rights is NOT even possible under US law where RF is a national resource that can only be licensed (for period of time, even if in practice that appears to be infinite) so exclusive licensed always will deviate from economic theory ideal of Coasian full-assignment of property rights followed by market negotiation....

While we did not include CBRS in our analysis, it is novel because it represents a model for transition. It is about sharing spectrum among multiple classes of users. Going to three classes of users drives to mechanisms and challenges that then can be expanded to more classes of users and a mechanism for updating rules for shared co-existence via linkage of markets and technical tools (i.e., SAS, which, as we have written previously, is itself a complex mechanism).

Focusing on Unassigned Spectrum as a broader class of options makes us recognize that the "assignment" of users to electrospace can often be done so that there is no need to exclude anyone (no rival, if coordination of use is feasible), and when exclusion is necessary (because of local context of market, legacy technology/infrastructure/switching costs, etc.). We need the breadth of the Unassigned Spectrum model precisely because we do not know how to design the technical ecosystem that new systems, uses and mechanisms anticipates. In the case of CBRS, the SAS ecosystem broadly construed will be a set of digital and analog (institutional, human, off-line) mechanisms and processes for managing property rights over spectrum use, which include operational decisions and economic decisions about investment, technology choice, etc., residual control rights, transferability, and rights to modify the rights system. At highest level, humans (as consumers, investors, employees, etc. – in businesses, government, etc.) will be in charge, but lots of actual decisions will be automated and how to architect the automation will determine who and how spectrum is controlled and managed. The failure to build in the flexibility to adapt governance (which is single most valuable feature of Unassigned Spectrum approach to governance design) is akin to problem of trying to bolt on security to an Internet that was designed without security built in.

What may be useful is to further explore how the concept of unassigned spectrum can be extended into a policy framework. In contrast to traditional command-and-control policy frameworks, a policy framework revolving around allocating unassigned spectrum bands recognizes a role for regulatory bodies in assisting spectrum-sharing arrangements when needed alongside the potential for such regulation to impose unnecessary costs associated with top-down control over governance practices. Unassigned spectrum, as a policy, avoids such costs by recognizing the potential for individual users of spectrum (whether they are indeed a single person or a community of users) to identify the best ways among themselves to allocate a valuable resource. Unlike the category of unlicensed spectrum, there is no presumption that the absence of a license is what necessitates spectrum. Indeed, one of the reasons why unassigned spectrum is a powerful category is because it recognizes both governance challenges inherent in licensed and unlicensed uses of spectrum as well as the capacity of communities of users of spectrum to govern its use, without relying on top-down rules.

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