Event Detection and Sharing of 6, 7 and 12 GHz bands

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Abstract

The scarcity of available spectrum bands has prompted the exploration and analysis of strategies for sharing spectrum with existing users. The US is considering several bands as part of its National Spectrum Strategy. In this paper, we consider sharing spectrum with the Broadcast Auxiliary Service (BAS) in the 6, 7 and 12 GHz bands. We develop simple models to examine the impact of interference in these bands to BAS-like operations. Our findings contribute to understanding the feasibility of various spectrum sharing regimes, such as, property rights easement, spectrum commons and spectrum anarchy. The key technical result of this study is that while new spectrum uses in the 6, 7, and 12 GHz bands can cause significant interference, this can be managed effectively through mitigation strategies such as dynamic exclusion zones, lower EIRP levels for indoor use, and advanced detection methods.

1 Introduction

Recently, attention has been directed at the lack of spectrum in the US for new commercial applications since most radio spectrum has already been assigned and allocated for other uses (federal, satellite, scientific sensing, localization, etc.). There are spectrum scarcity problems outside the US as well, but a second challenge facing the US is the perceived descent in US leadership in wireless communications and the challenge posed by potential adversarial nations. Consequently, there has been increasing emphasis on the strategies that can be adopted to accelerate innovation in radio spectrum. The FCC Notice of Inquiry [1] on expanding the use of the 12.7 GHz bands, the recent FCC proposed rule in the 6 GHz bands [2, 3], and National Spectrum Strategy Implementation Plan [4] consider spectrum in the 6, 7 and 12 GHz bands (among others) as opportunities for sharing spectrum. Developing efficient methods for spectrum sharing is considered imperative for the US to maintain leadership in wireless communication. An important existing use of these bands is for the incumbent Broadcast Auxiliary Service (BAS) [5, 1] which includes remote TV transmissions during events of importance, both scheduled and unpredictable events – e.g., announcements by government officials, accidents, weather events, etc.

Here, we build simple models to examine the impact of interference in these bands to BAS-like operations. Our goal is to consider the impact of transmit power, different usage scenarios (e.g., indoor and non line-of-sight versus outdoor), and finally to consider the use of event detection and central or decentralized notification toward sharing spectrum in these bands. This work informs the potential for different spectrum sharing regimes such as property rights easement, a polycentric system of spectrum management as suggested by Elinor Ostrom's research on governance of commons [6, 7], and spectrum anarchy, whereby participants themselves coordinate on alternative rights arrangements.

The paper is organized as follows. In Section 2 we provide background on the spectrum bands of interest, Broadcast Auxiliary Service, event detection and localization and spectrum regulatory regimes. Section 3, presents the model and analysis of BAS. In Section 3.3 the model is used to study BAS spectrum sharing with event detection. In Section 4, we show that event detection enhances spectrum sharing efficiency by creating temporal exclusion zones to reduce interference during scheduled unpredictable events, utilizing strategies like lower transmission power, hybrid sharing models, and social sensing to optimize spectrum use without compromising essential services. Section 5 contrasts distinct methods for managing spectrum sharing, including spectrum sharing (relying on government coordination), spectrum commons (emphasizing self-organization and equitable access), and spectrum anarchy (allowing for real-time, market-driven access without predefined rules). Sections 6 and 7 discuss limitations and conclude, respectively.

2 Background

2.1 Spectrum Sharing Bands of Interest

Many discussions and reports in the last years have emphasized the need for sharing spectrum between incumbents (currently assigned users) and new uses of spectrum. In this section we highlight the three bands we consider in this paper that have been suggested for spectrum sharing.

The 6 GHz Spectrum: The 6 GHz spectrum has been purposed for unlicensed use in the US. As shown in Figure 1, there is 1200 MHz of spectrum, divided into the so-called Unlicensed National Information Infrastructure (U-NII) bands. There are incumbents in these bands that include satellite and fixed services (FS). Fixed services are point-to-point microwave links. The U-NII-8 band (see Figure 1) is used by TV stations for local news, sports, and unpredictable events such as weather and road closures [8]. In particular, 25 MHz channels are used for BAS.

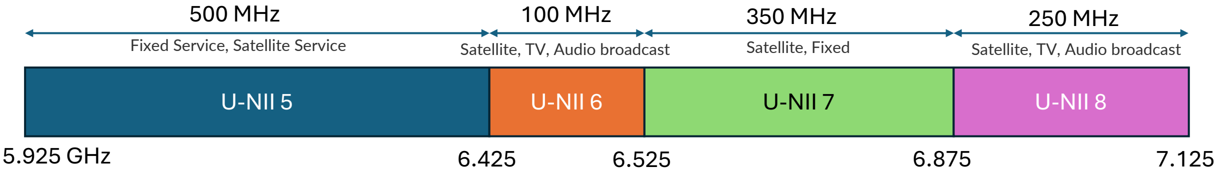

Figure 1: The allocation of spectrum in the 6 GHz bands in the US

The 7-8 GHz Spectrum: While the UNII-8 bands do overlap with 7 GHz (6.875-7.125 GHz), the band that is just above is commonly referred to as the 7-8 GHz spectrum. It ranges from 7.125

GHz to 8.5 GHz for a total of 1.375 GHz of spectrum. As noted in [9], about 20% of this spectrum is used by the Department of Defense and satellite operations, while other uses of this spectrum are primarily due to fixed services (FS), and fixed and mobile satellite services. Slices of this band are used for uplink and downlink by earth exploration satellites. For example, the 7.19-7.25 GHz slice (600 MHz of spectrum) is used for uplink and 8.025-8.125 GHz is used for downlink transmissions. As mentioned above, fixed services are point-to-point microwave links. As noted in [9], an example federal use of this spectrum is to "connect remote aeronautical radio-navigation radars to air traffic control centers" by the Federal Aviation Administration using such microwave links. Interestingly, already, unlicensed extremely low-power use of the 7.75–8.75 GHz spectrum for Ultra-WideBand (UWB) is allowed. Also, in this spectrum, several bands are used for mobile satellite services (e.g., downlink in 7.25-7.3 GHz) which may benefit from detection of mobile earth station activity as their locations may change with time.

The 12 GHz Spectrum: The 12.2-13.25 GHz of spectrum is being considered for sharing, with current incumbents including satellite uplink, fixed services and mobile services [9]. The mobile services in this band includes TV Pickup transmissions as noted in [8]. FCC rule 74.602 does the frequency assignment in these bands. Channels are 25 MHz wide, although the 13.15-13.20 GHz slice, reserved for television pickup, may be used by earth stations outside a 50 km zone of specific TV markets.

We do not consider the fine details of the allocation of each band in this paper, but focus on the 50 km radius of TV metro markets where we expect substantial demand for spectrum.

2.2 The Broadcast Auxiliary Service

As mentioned above, spectrum is allocated in metropolitan markets for the broadcast auxiliary service. Here, TV Pickup vehicles broadcast recorded or live video from locations when there are events of interest. Recorded video should not pose a spectrum sharing problem since such video can be transferred to the TV stations when the pickup vehicle returns. Live transmissions are the ones subject to potential interference.

Live transmissions are received by antennas in TV stations, typically at a significant height as described in [8]. Also as described there, such antennas are receive-only. Further, TV pickup vehicles use estimates and experience to point their antennas in a manner that allows transmissions to be successful and of good quality. For example, they may bounce off nearby buildings [8]. Many local event locations are known (e.g., local government office or landmarks).

Live transmissions are mostly scheduled in certain time windows (e.g., the local news between 5.00 and 6.00 p.m. or 10.00 and 11.00 p.m.). Unpredictable events for breaking news are more challenging in terms of spectrum sharing.

However, there are many opportunities for sharing since there are several 25 MHz channels available for BAS. Further, as BAS services increasingly use digital video transmissions (e.g., Digital Video Broadcast Terrestrial – DVB-T), the bandwidth needs may be substantially reduced. DVB can transmit MPEG video streams in 6 MHz channels using QPSK, 16-QAM and 64-QAM with error correction using Reed-Solomon codes. More powerful coding schemes (BCH and LDPC) and 256-QAM are used in the DVB-T2 standard. While we do not analyze these specific physical layers in the paper, they provide opportunities for adaptively changing the modulation and coding schemes to the level of interference in the spectrum.

2.3 Event Detection and Localization

Spectrum usage by TV Pickup (e.g., Electronic News Gathering or ENG) is the scenario that requires event detection, although a flexible allocation of spectrum usage in the future may also make use of event detection for other applications.

Protecting BAS services requires a rapid indication of the location of the events so that coexistence mechanisms may be applied (such as channel hopping or reducing power or dynamically creating exclusion zones) to prevent harmful interference. Approaches for sharing that go beyond periodically checking a database (e.g., FCC's Universal Licensing System) can improve spectrum efficiency.

Recent work (e.g., [10]) allows social sensors to localize unpredictable events. When such events occur, people often report them on microblogging, news, or other social media sites that allows localization of events. With localization of the event and known locations of the TV station receivers, it is then possible to trigger spectrum coexistence options. Some challenges exist with this approach resulting in false positives or negatives. There may be problems in understanding the semantics of microblogs and whether they are relevant to the local situation. If simple counts of microblogs are used [10] with approximate locations of sensors in the local area, it is possible to miss peaks in the time series of microblog counts. It is also possible to select "false" peaks that trigger co-existence mechanisms reducing spectrum efficiency.

2.4 Regulatory and Policy Regimes

Exclusive licensing was proposed in the 1950s as an alternative to assignment through hearings [11, 12]. With spectrum sharing, spectrum ownership is established by the government. In the US, this occurred in 1927 when the Congress, with the Radio Act, stated that the government would manage spectrum in the public interest [13]. The previous period was considered anarchy, with challenges with interference as more broadcasters entered the market in the 1920s [14]. Since then, the question has always involved the specific property arrangements to government spectrum. The extent to which the FCC has monopolized authority has led some to consider a thought experiment of what might occur if the FCC were abolished [15, 16]. Since property can be conceptualized as a bundle of rights (or bundle of sticks), it is possible to divide and subdivide property rights [7].

More recently, analysis of spectrum as a commons recognizes that the radio frequency spectrum is a finite resource that can be overused or mismanaged if not governed effectively. Drawing from Elinor Ostrom's research on the governance of common resources [6, 7], spectrum sharing requires a framework that balances the interests of various users to prevent interference and depletion of the resource, much like managing water rights or fishing grounds.

In this context, treating spectrum as a commons means that while no single entity owns the spectrum, its usage must be regulated to ensure that all stakeholders have fair access and that the spectrum is used efficiently. Innovative sharing arrangements, like the ones being considered for the 6, 7, and 12 GHz bands, attempt to create such a governance structure. These arrangements enable multiple parties to use the same spectrum by implementing rules and mechanisms that govern access, such as dynamic spectrum access systems, event detection and localization, and policies for creating exclusion zones.

This communal approach ensures that the spectrum is managed in a way that maximizes its value for society, rather than being dominated by a few powerful entities. It requires a careful analysis of how the spectrum is used, the potential for interference, and the development of sophisticated technologies and policies that allow for its shared use without compromising the quality of service for any user. The concept of the spectrum as a commons emphasizes the need for cooperative stewardship and the development of innovative policies that support both the current needs and future advancements in technology, while considering the public interest and national priorities such as security and economic growth.

Meanwhile, CBRS pioneered a three-tiered sharing model that incorporates incumbent users, Priority Access License (PAL) holders, and General Authorized Access (GAA) users, managed by a Spectrum Access System (SAS). Similarly, the proposed arrangements aim to enable efficient use of the spectrum by various stakeholders through dynamic sharing mechanisms. In the case of the 6 GHz band, which has been opened for unlicensed use, the approach mirrors the GAA tier of CBRS, where users can operate without individual licenses but must not cause harmful interference to incumbent services.

The Automated Frequency Coordination (AFC) approach [17], also requiring device certification, is used with standard power operations in the 6 GHz bands where incumbent point-to-point microwave links also operate. The idea here is to use a database of incumbent locations and the Winner II[1] radio propagation model to create exclusion zones for outdoor operation of WiFi in the 6 GHz bands. The Open AFC Software Group [19] is working toward AFC software tools to support WiFi operation in the 6 GHz bands. Recently, the FCC has asked for comments on the use of local geofencing decisions with even larger transmit powers (up to 1 dBm/MHz EIRP PSD and up to 14 dBm EIRP) that will allow 14 dBm of transmit power in channel bandwidths of 20 MHz, not just 80 MHz channels. This is an example of a slow process to allow higher efficiencies in spectrum usage. We note this is a conservative, everywhere deployed mechanism (limited polycentricity), relying on device certifications for enforcement.

3 Model and Analysis

In this section, we consider a simple model for understanding the possibility of sharing spectrum between incumbents and new uses. For new uses we consider two possibilities - a CBRS like 5G service and a WiFi like unlicensed service. For the former, we will assume the following:

- Device transmit powers of 23, 30 and 47 dBm EIRP. This is similar to CBRS devices.
- An activity factor, similar to the new CBRS 2.0 notice [20], but the actual factor is tuneable.

For the latter, we will assume the following:

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[1] The Winner II channel models consider several scenarios, cell types, indoor, outdoor, outdoor-to-indoor etc. in the 2-6 GHz bands. See [18].

- The FCC currently specifies an EIRP of 14 dBm in the upper 6 GHz bands [2]. There is a request for comments for increasing this to 21 dBm. We ignore the details of how the EIRP should be distributed in bandwidth (-5dBm/MHz or higher - up to 1 dBm/MHz). We will use the 14 dBm and 23 dBm EIRP values (instead of 21 dBm to keep it the same as CBRS).
- As an upper limit, we will also consider a 30 dBm EIRP for Wi-Fi like services.

Finally, we will consider an outdoor cellular like system with an EIRP of 50 dBm (100 W) [2]. We will look at an EIRP of 30 dBm as the middle value in a range of possibilities in the following subsections.

We also assume that receive sites are stationary and "known" though the FCC's Universal Licensing System or another database like AFC or a SAS.

3.1 Path-Loss Models

Path-loss models are important to assess interference and thus isolation strategies for sharing spectrum. While path-loss models exist for the upper 6 GHz bands, it is only recently that there has been attention placed on the FR3 bands (> 7 GHz). For instance, there are very few measurements and models reported in the 10-13 GHz bands. In [21], measurements at 10 GHz were done with an EIRP of 23 dBm (which is smaller than that suggested for the UNII bands by the FCC). In line-of-sight (LOS) situations, the path-loss followed the free space model (20 dB per decade of loss) as it did in non-LOS (NLOS) situations (which had an additional loss of 15-20 dB). Over a distance of around 30m, LOS and NLOS measurements showed a path-loss of 80 dB and 95 dB respectively. These measurements suggest that the interference in these bands are unlikely to be substantial at large distances.

In this paper, we consider path-loss at 7 and 13 GHz based on the models analyzed in [22, 23]. **We assume that the 7 GHz path-loss model will apply to transmissions in the U-NII-8 band (see Figure 1) and the 13 GHz path-loss model applies to the 12.2-13.25 GHz band**. In [22], empirical models are considered at 7 and 13 GHz based on a variety of measurements under line-of-sight (LOS) and non line-of-sight (NLOS) conditions. The free space model can be considered to be the *worst-case* path-loss where the loss is the lowest from an interfering transmitter and thus causing the highest interference. The general equation of the free-space loss is:

$$L_p = 21.98 - 20\log_{10}(\lambda) + 20\log_{10}(d) \tag{1}$$

where $\lambda = c/f$ is the wavelength, $c = 3 \times 10^8$ m/s is the speed of light, f is the frequency (7,13 GHz) and d is the distance (in meters) from the transmitter under consideration.

The work in [22] also has a best-fit model and what we can consider to be the best-case model (NLOS) where the loss is the highest and interference is the lowest. These models are given by:

$$L = \alpha + 10\beta\log_{10}(d) \tag{2}$$

where α and β were derived empirically based on measurements. We refer the reader to [22, 23] for the measurement set-up, equipment, antenna placement and other details. Our goal here is

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[2] See for example https://www.fcc.gov/consumers/guides/human-exposure-radio-frequency-fields-guidelines-cellular-and-pcs-sites

Frequency	α	β
7 GHz	74.7	2.04
13 GHz	80.6	1.78

Table 1: Path-Loss Model Parameters from [22]

not to analyze these models, but to use them to understand the prospect for sharing under event detection. We summarize the values of α and β in Table 1. We note here that the intercept with the NLOS model is “floating” and does not match that of the free-space path-loss model.

Figure 2 shows the path-loss between 100m and 5km based on the free-space loss and the NLOS empirical model. We make the following observations:

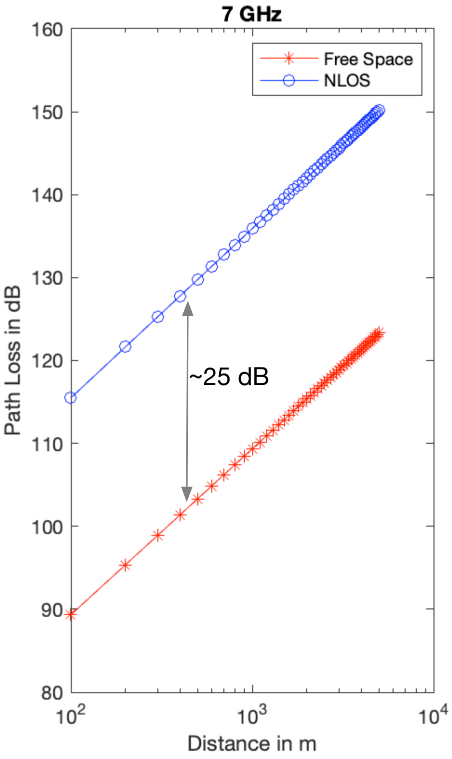

Figure 2: The best and worst case path-loss we use in this paper

- There is a 20-25 dB difference between the free-space and NLOS models depending on the frequency. This extra loss is attributable to NLOS conditions, clutter and the underestimate of path-loss in (1). In [22], around 90% of locations are NLOS.
- While [22] provides a path-loss model that has a reference distance of 1m, we assume that the 100m distance is sufficient as any interference to the BAS receiver is likely to be coming from a transmitter that at least 100m away as explained in Section 3.3. Moreover, the model with the reference distance is not as accurate as the one we use here.
- The FCC suggests the Winner II models towards creating exclusion zones as already dis-

cussed. The Winner II models are shown to be useful as upper or lower bounds of path-loss [22], but either overestimate (assume larger loss than measured) in NLOS conditions or underestimate the loss otherwise. We thus use the free-space and NLOS models from [22] as described above.

3.2 Analysis of Interference

We analyze the interference with and without event detection in this section by looking at various scenarios. We can consider two different metrics: (i) the interference/noise ratio to be -6 dB (or the interference power is at least 6 dB lower than the noise level). (ii) received power from interfering transmitters is -85 dBm or lower. We pick -85 dBm (and a lower number of -95 dBm) below because for services such as WiFi, the minimum required RSSI for reasonable communication is about -80 dBm.

Further, we do not have a good model for the required BAS reception powers. However, we make the following assumption. The required carrier to noise ratio for DVB-T ranges from 4 dB to 28 dB based on the modulation and coding scheme used [24]. We assume that the noise power is around -100 dBm. If we make these assumptions, BAS transmissions could have substantially lower received power than the interfering transmissions (espectially at a 4 dB C/N ratio). If we use the -6 dB I/N value, it will need active exclusion of secondary services almost always (or where possible as an event is detected).

First we consider interference assuming *no mitigation approaches in place*. We could think of this as a form of spectrum anarchy. From Figure 2, the loss at 100m in the worst-case (free-space) model is 90 dB at 7 GHz and 95 dB at 13 GHz. We assume the former for the U-NII-8 bands and the latter for the 12-13 GHz band. With an EIRP of 30 dBm, even with this large path-loss, transmissions can still pose interference to BAS receivers as the received power at the BAS antenna from an interfering transmission can be -60 to -65 dBm. At this interference level, it would be impossible to operate a secondary service without any restrictions.

EIRP	Worst Case Interference Power	Best Case Interference Power	Sharing Potential
14 dBm	-76 dBm	-96 dBm	Indoor usage possible
23 dBm	-67 dBm	-87 dBm	Indoor usage possible
30 dBm	-65 dBm	-85 dBm	Indoor usage possible
47 dBm	-43 dBm	-63 dBm	Exclusion Zone of 1 km for indoor use

Table 2: Situation without any Mitigation/Coexistence Applied for Indoor Use

If the interfering transmitters are inside a building, as is the requirement for 6 GHz transmissions, an additional 20 dB loss makes it possible to transmit *without any restrictions* at lower transmit powers[3]. As shown in Table 2, except for a transmit power >30 dBm, under NLOS conditions, the received power from most transmissions at both 7 and 13 GHz would result in an

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[3] One would anticipate that TV stations would not deploy Wi-Fi like or other interfering services in these frequency bands in their own facilities.

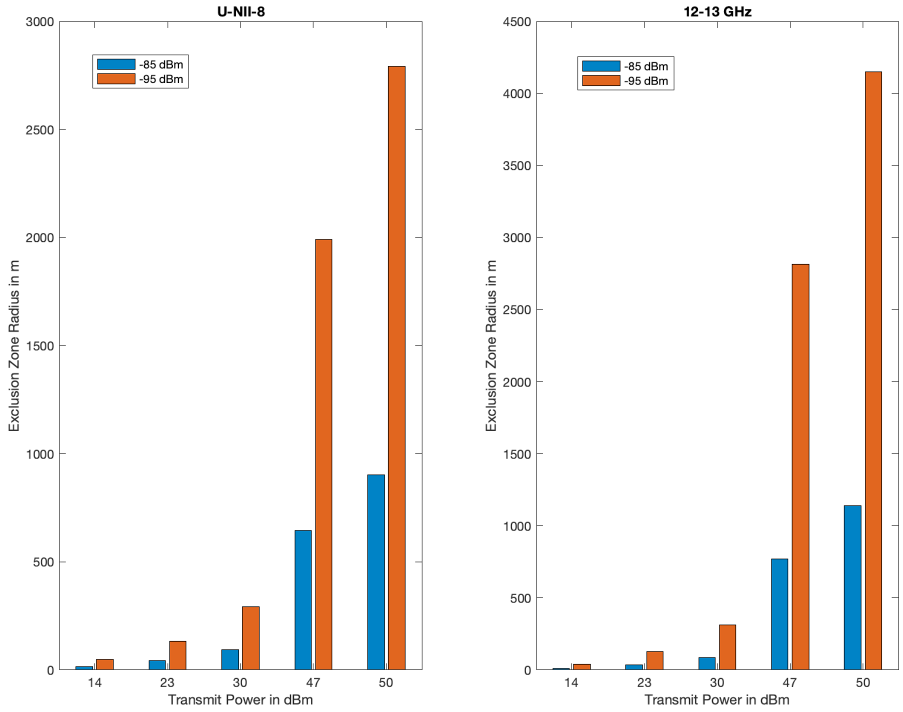

Figure 3: Exclusion zone radii in the U-NII-8 and 12/13 GHz bands assuming the path loss model in Table 1 and received interference power level at -85 dBm and -95 dBm

interference power of -85 dBm or lower.

If CBRS devices with a transmit power of 47 dBm are deployed, exclusion zones will become necessary. In order to have a path-loss of 132 dB, an NLOS transmitter with a transmit power of 47 dBm will have to be at a distance of 644m (U-NII-8) and 772m (12-13 GHz). The longer distance at 12-13 GHz is due to the lower path loss gradient of $\beta = 1.78$ in Table 1. We suggest an exclusion zone of 1 km based on these results. Even at a 50 dBm transmit power, if the transmitter is indoor (NLOS), the exclusion zone radii will be 1.14 km in the U-NII-8 and 903m at 12-13 GHz.

Naturally, the exclusion zone radii increase substantially if the acceptable interference levels are lower (for example -95 dBm). Figure 3 shows the radii of the exclusion zones with different transmit powers in different bands assuming the acceptable received power is -85 dBm and also with -95 dBm. The largest exclusion zones are between 2 and 5 km for the highest powers. With smaller transmit powers (14 and 23 dBm), it is possible to operate in NLOS (e.g., indoor areas) without restrictions. Purely outdoor operations would be precluded without co-existence mechanisms in place.

As shown in Figure 4, the exclusion zone radii become exceedingly large if the radio propagation characteristics are more similar to free-space loss. Even at higher acceptable interference levels (-85 dBm), the exclusion zone radius with a transmit power of 47 dBm is 14 km in the U-NII bands and 10km in the 12-13 GHz bands. Interestingly, the exclusion zone radii is larger in the U-NII bands in this scenario compared to 12-13 GHz unlike the scenario where radio propagation is NLOS (Table 1). This is because the path-loss intercept is higher at 12-13 GHz with free-space

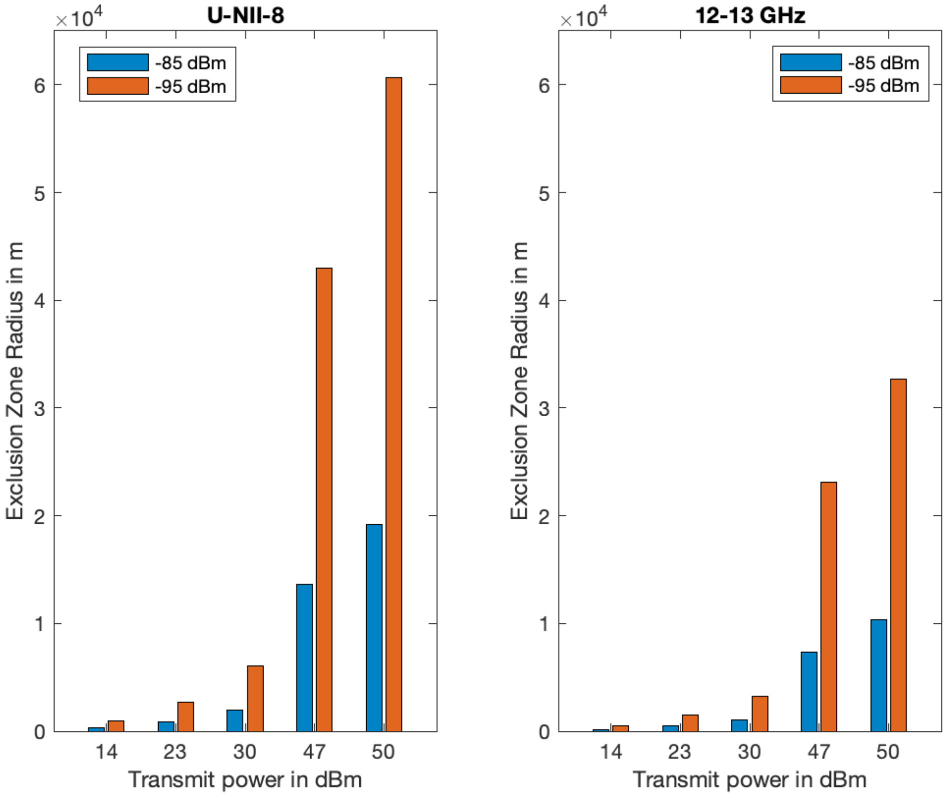

Figure 4: Exclusion zone radii in the U-NII-8 and 12/13 GHz bands assuming free-space path loss model and received interference power level at -85 dBm and -95 dBm

propagation and the attenuation with distance is 20 dB per decade of distance in both cases. With NLOS propagation, while the initial loss is higher at 12-13 GHz again, compared to the initial loss in the U-NII-8 bands, the attenuation with distance has a smaller gradient (17.8 dB/decade vs 20.4 dB/decade). At the lowest transmit power (14 dBm), it may be possible to deploy transmitters outdoors at 12-13 GHz as the exclusion zone radius is around 160m. In the U-NII-8 bands, the radius is around 300m.

3.3 Using co-existence mechanisms

We examine the impact of co-existence mechanisms using some simple models. We assume that the metropolitan area A_m of consideration is a circle of radius $r_{max} = 50$km. This corresponds to an area of $A_m = 7854\text{km}^2$. There are as many as 23 full-power TV stations in New York City, 9 in Pittsburgh and 10 in Tucson[4]. We assume an average of $N_s = 10$ stations per market.

3.3.1 Exclusion Zone Efficiency

Let us suppose that an AFC-like approach is used for geofencing transmissions in a metropolitan area. Using a path-loss model (be it the Winner II model or an empirical measurement based

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[4] See https://www.stationindex.com/tv/tv-markets

model like the one in Table 1), transmitters can determine whether they are allowed to transmit based on their locations and the locations of BAS receivers through exclusion zones.

With N_s stations, and an exclusion zone radius of r_x, the total excluded zone will be $A_x = \pi N_s r_x^2$. Thus the spatial efficiency can be written as:

$$\eta_{spatial} = 1 - \frac{A_x}{A_m} = 1 - \frac{N_s r_x^2}{r_m^2} \tag{3}$$

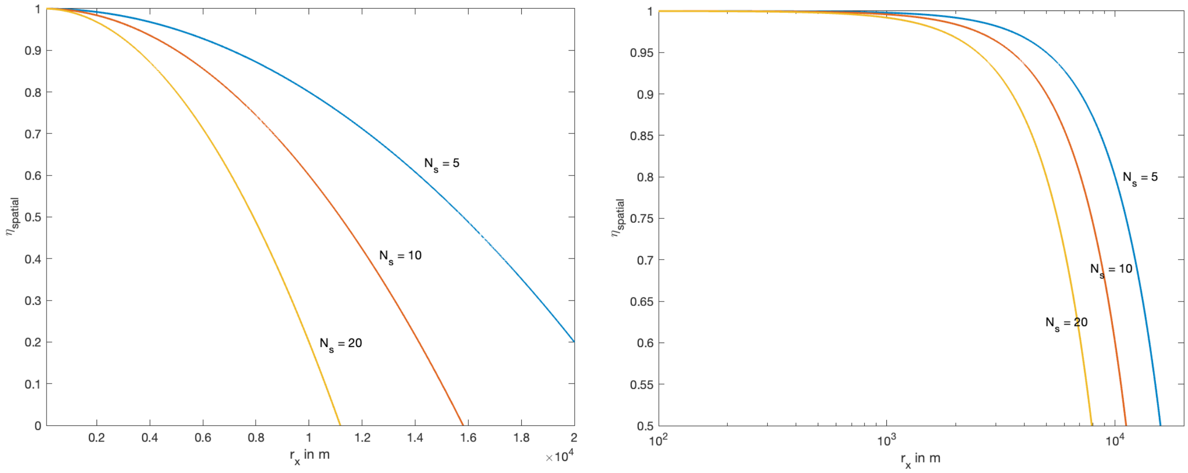

Figure 5: Spatial efficiency as a function of exclusion zone radius for different numbers of TV stations (zoomed in on right)

As shown in Figure 5, for a large number $N_s = 20$ of TV stations, the efficiency of spatial sharing drops rather quickly. If one were to assume that most TV stations are located at vantage points in a metropolitan area, we could approximate the exclusion zones to be overlapping rather than separate. In such a case, with $N_s = 5$, high spatial efficiencies are possible with moderate exclusion zones of 1-10km. Zooming in, we see that even for large numbers of TV stations, an exclusion zone of 1km would result in large spatial efficiencies suggesting the suitability of indoor use of both spectrum bands with the spectrum anarchy model. However, a centralized implementation of larger exclusion zones could still provide substantial efficiencies in spatial sharing.

3.3.2 Adding an Activity Factor

In the CBRS 2.0 notice from the NTIA to the FCC [20], a 80% TDD activity factor and 20% network loading factor was used to reduce the impact of each transmitter's power by about 8 dB. In our model, we could assume a 10 dB effect to use the lower threshold of -85 dBm in Section 3.2 or a further reduction in this threshold by a factor of F_a dB. We show the effect in Figure 6. We assume the path loss models from Table 1. Clearly, with a transmit power of 23 dBm, a moderate $F_a = 8$ dB would reduce the exclusion zone to less than 100m and at 47 dBm, to around 400m. Both would yield larger spatial efficiencies. Again, what is noticeable is that the initial loss in 12-13 GHz bands is higher, but subsequent losses with distance are slower than in the U-NII-8 bands. This accounts for the discrepancy in the radii of the exclusion zones needed for these bands with different transmit powers and activity factors. For example, the exclusion zone radius is larger for the U-NII-8 bands with a transmit power of 23 dBm but slightly smaller with a transmit power of 47 dBm compared to the corresponding radii for the 12-13 GHz bands.

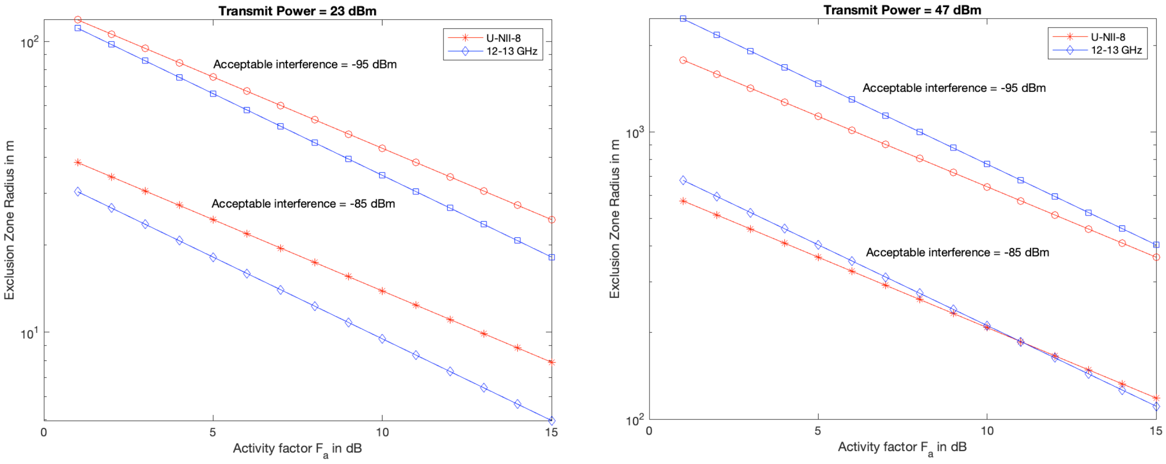

Figure 6: Reduction in exclusion zone radius assuming an activity factor that reduces the interference by F_a dB for two levels of acceptable interference of -85 dBm and -95 dBm (left) transmit power = 23 dBm (right) transmit power = 47 dBm

4 Event Detection and Spectrum Sharing

When exclusion zones are so large as to reduce the spatial efficiency, event detection will allow better utilization of the spectrum by creating “temporal exclusion zones” rather than only ”geographical exclusion zones”.

Consider scheduled events like the local news. During such periods, a priori, interfering transmitters can adopt several strategies to reduce interference to BAS receivers. They include:

- As seen in Section 3.2, using a lower transmit power can allow operations without interference, especially in indoor areas. By adopting this strategy, interference to BAS receivers can be reduced. During such scheduled times, mobile services can use the bands as supplementary channels rather than primary anchor channels.

- If a ”hybrid sharing model” [25, 26] where the same bands can be used for licensed and unlicensed services can be used, during scheduled event times, devices that are indoor-only unlicensed services can operate while outdoor services would be paused.

- We observed in Section 3.3.2 that the exclusion zone radius can be drastically reduced if the activity factor F_a is larger. If the shared spectrum is allocated to mobile operators, it is possible that the operators can offload low duty-cycle IoT traffic from their exclusive spectrum to shared spectrum. Thereby, freeing up more exclusive spectrum for mobile broadband like services.

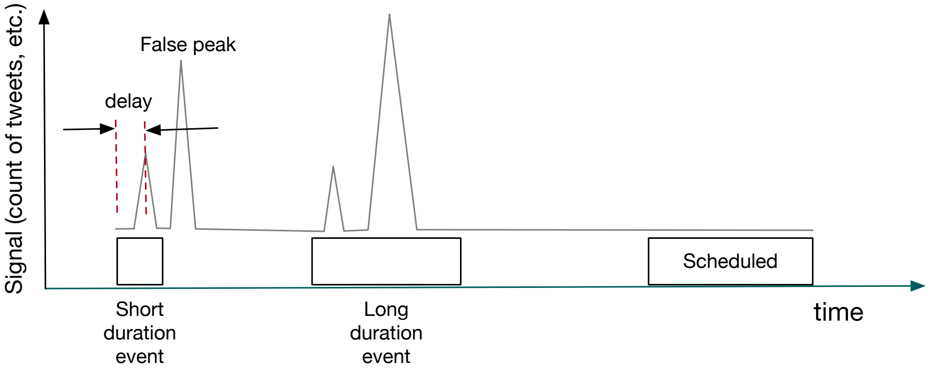

Figure 7: Event Detection Problem

Databases such as SAS/AFC or even local decision based operations should have mechanisms in place to accommodate scheduled events.

When there are unpredictable events that have not been scheduled, such as weather, accidents, or breaking news, there are certain possibilities for event detection. In a manner similar to CBRS, it is possible that TV stations use an incumbent information capabilty (IIC) to report their need for using BAS receivers to a SAS or AFC-like database.

As described in Section 2, social sensing can be used by secondary transmitters to automatically detect potential events. This approach would be similar to the Environment Sensing Capability (ESC) in CBRS. However, this approach has several challenges:

- In CBRS, a CBSD has to actively seek a grant to transmit. The potential rarity of unpredictable events that also need TV pickup transmissions may make an active grants to transmit an extra overhead. This will also create a burden for SAS-like databases [27].
- As shown in Figure 7, simple counts of micro-blogs create two types of problems. For short duration events, the latency to detect the event may cause the event itself to be missed. Alternatively, the event may generate a peak long after the duration is completed as the event generates chatter on social media.
- Since event sensing is similar to ESC, it begs the question whether DVB-T transmissions by BAS can be sensed. Work in TV white spaces has considered this problem [28], although it is not clear whether it would work for BAS transmissions which are directed differently. A combination of social sensors and environment sensors may prove to be more robust for event detection.

One possibility is to have some type of incremental redundancy, a concept that has been examined in cellular networks [29]. In cellular networks, the highest code rate is used to transmit packets and if necessary a higher power or lower code rate is adopted when packet losses are detected. In the same way, secondary transmissions could alternate between high and low activity factors while polling a database for events.

5 Policy Considerations

5.1 Centralized Control

In certain bands like the lower 37 GHz band and the 2025-2110 MHz band, the incumbent military use requires coordination for access in specific locations. This approach relies on agreements and an understanding of when and where the military operations occur, which may involve manual coordination rather than real-time, dynamic systems. In the lower 37 GHz band, the incumbent is the military. The current arrangement is coordination for specific locations where military operations occur. The FCC has established a framework for sharing and is developing service rules under a pending proceeding. The 2025-2110 MHz band involves an incumbent with broadcasting, with military access to specific locations involving coordination on occasion. The arrangement is based on a memo of understanding between the Department of Defense (DoD), the National Association of Broadcasters, and the Society of Broadcast Engineers.

Each of these methods balance the diverse needs of national security and commercial growth. Each method has its own sets of rules, technologies, and processes designed to optimize the use of spectrum. The arrangements above each have a significant role for government to manage spectrum. Governments determine the priority users as well as the rights of secondary users. Government typically is the enforcer of coordination agreements.

For the U-NII-8 GHz and 12 GHz bands, the emphasis is on creating innovative sharing strategies that protect existing services like BAS while allowing new users to access the spectrum. This might involve event detection, central or decentralized notification systems, and real-time coexistence mechanisms, akin to the SAS in CBRS that coordinates users and prevents interference.

Several arrangements can improve prospects for innovation within a system of centralized sharing. A possibility with centralized spectrum management is for regulatory bodies to consolidate bands for use by BAS or in the extreme case to relocate BAS as was once done by Sprint [30]. Digital video transmission with good quality is also possible with 5G and certainly emerging 6G services. Instead of using dedicated spectrum inefficiently, it is possible that TV pickup could interface its video transmissions through cellular service providers, who could, in return for the freed-up spectrum, provide priority access to TV stations in the metro markets.

Another potential arrangement is property rights with easements, which may provide a structured yet flexible framework for spectrum access, much like the tiered rights in CBRS. An easement arrangement relies on the "bundle of sticks" approach to property rights.

A bundle-of-sticks property rights approach views spectrum as a collection of individual rights (or sticks) that can be separately owned, transferred, or leased. This approach allows for flexible arrangements where different rights, such as the right to transmit at certain times or in specific geographic areas, can be parceled out and managed individually and independently.

Property easements in spectrum sharing involve granting a secondary user the right to use a portion of the spectrum under specific conditions, without transferring full ownership of those rights. Easements provide a way to allow incumbents to allow other users of spectrum, while the incumbents retain overall control. In this way, secondary users acquire rights to use part of the spectrum that is controlled by incumbents.

A bundle of sticks property rights approach can contribute to more flexible spectrum access, allowing incumbents to grant easements for secondary use, thus balancing protection of property with innovation. For example, TV pickup licenses could rent their licenses under a local licensing model, enabling other users to temporarily access the spectrum while maintaining overall control. Such arrangements recognize that property rights can be divided and subdivided within an overall system in which an incumbent is considered the owner of that part of the spectrum. Through such an approach, centralized control with easements can together enhance spectrum efficiency and adaptability, thereby contributing to technological advancement in a context of increasing spectrum scarcity. This could potentially allow for a balance between the protection of incumbents and the facilitation of innovation in spectrum use. Overall, these arrangements aim to enhance spectrum efficiency and adaptability, ensuring that spectrum scarcity does not hinder technological advancements or U.S. leadership in wireless communications.

5.2 Spectrum Commons

A second approach draws on Elinor Ostrom's research [6, 7] on commons governance. A significant aspect of the Ostromian approach is emphasis on polycentric features of spectrum management [31]. Polycentric systems have as their defining feature self-governing within an overarching system of control. Such an exploration suggests a move towards self-organization and local problem-solving in spectrum management, which is a shift from the traditionally more centralized approach of spectrum allocation. An example is amateur radio, where self-governance is used, including etiquette rules, to manage access to spectrum [31]. It is polyentric in that the overall systems of spectrum is governed by the FCC, though amateur radio operators and thier local communities of users have significant opportunities to govern themselves.

These Ostromian perspectives suggest several ways to improve management of spectrum in such contexts. Some of these include the following:

1. Creating more equitable access to spectrum, such as by including more users in spectrum sharing arrangements.
2. Decentralization of authority to manage spectrum, such as by enabling the users to devise their own sharing arrangements once they are authorized to use spectrum.
3. Refining and improving technology to enable more efficient sharing, including more effective detection of events.

The idea behind (1) is that there are often groups excluded from spectrum management. An example is exclusion of tribal and Indigenous communities from national systems of spectrum management [32, 33]. Regarding (2), there are many ways to extend property arrangements. Some rely on increasing use of unassigned spectrum as a conceptual framework since this enables groups to an extent to develop their own rules [34]. For (3), the idea is simply that technology influences the opportunities to share spectrum and hence can, when deployed, increase prospects for greater self-management by enabling users to better detect events that can undermine a sharing arrangement.

An aspect of coexistence with minimal co-ordination that we have not considered in detail in this paper is the question of channelization and overlap where spectrum users may self-organize.

BAS employs multiple 25 MHz channels although DVB-T broadcasts can now use smaller bandwidths, even on the order of 5 MHz. Wi-Fi can use anywhere between 20 and 320 MHz of bandwidth in multiples of 20 MHz. Similarly, there is flexibility in channelization in 4G/5G services. There has been some work in [35] and [36] on interference between DVB-T and LTE on the uplink and downlink respectively. In [35], error rates in DVB-T as a function of the signal to LTE interference ratio is examined for partial and full channel overlaps. Extending this to the impact of 5G-NR signals and a consideration of the appropriate exclusion zones and activity factors is necessary to assess what kinds of decentralized sharing mechanisms would be appropriate.

In the case of Wi-Fi like secondary use, one possible approach for reducing harmful interference would be to allow dynamic manipulation of the Clear Channel Access (CCA) threshold [37]. This threshold suggests the received signal strength value at which a device backs-off from transmission. If spectrum users can self-organize, adjusting the CCA threshold could artificially shrink the coverage of Wi-Fi access points.

5.3 Spectrum Anarchy

A third general approach is spectrum anarchy. The concept of spectrum anarchy extends beyond a commons governance perspective through its emphasis on developing systems that enable more creation of rules by the participants [38]. In essence, spectrum anarchy considers the possibility of emergence of rules from the bottom-up, without relying much, if at all, on a centralized authority to determine the specific rules that govern sharing arrangements.

Considering scenarios of spectrum anarchy where governance of spectrum is centralized but sharing is possible in real time, without reliance on government to assign rights [38] is possible. Spectrum anarchy offers a more fluid, market-driven access to spectrum, somewhat similar to the real-time decision-making capabilities of SAS but without the need for such a system. Using the AFC approach or with indoor-only operation, as discussed in Section 3.2, at low transmit powers it may be possible to simply allow self-governance of spectrum with a Wi-Fi like technology.

If spectrum anarchy were to result in interference to the point that BAS transmissions are not of sufficient quality, TV stations could also rely on user generated footage [39]. Increasingly, news stations, and even mainstream news employs short videos uploaded by users either directly or to sites like X (formerly Twitter).

6 Limitations of this work

In this work, we assumed a single transmission being the major contributor for interference. This is reasonable for Wi-Fi like transmissions where backoffs in a channel preclude multiple transmissions at the same time and for CBRS like transmissions where it is common to have some planning to allocate different channels to geographically proximate access-points or base stations. However, the models may be optimistic with dense and mobile deployments that may need extensive measurements to characterize the effect of aggregate interference. For example, the work in [40], one of the first measurement campaigns of actual deployment, looks at dense Wi-Fi 6E deployments in the upper 6 GHz bands and concludes that for the most part, indoor transmissions do not leak outdoors, but some leakage occurs in a small number of cases.

7 Conclusion

In this paper, we explored the feasibility of spectrum sharing in the 6, 7, and 12 GHz bands with BAS operations. Path-loss models show that new spectrum uses can cause interference, though risks may be manageable through a variety of mitigation strategies, such as channel hopping or power reduction.

From a regulatory and policy framework, systems for managing spectrum such as the three-tiered CBRS system or AFC could be adapted for the bands under consideration. One possibility is adopting centralized control for certain bands, using a ”bundle of sticks” approach to property rights for added flexibility, and encouraging a polycentric approach for decentralized and equitable access. Spectrum anarchy, which allows market-driven access with minimal centralized control, could also be supported by technologies like AFC and low-power indoor operations.

The feasibility of sharing spectrum with BAS in the 6, 7, and 12 GHz bands is viable under specific conditions. Key implications include the potential for indoor usage with lower EIRP levels and the creation of dynamic exclusion zones to protect BAS operations. Advances in digital video broadcasting (DVB-T and DVB-T2) offer opportunities for adaptive modulation and coding, further enhancing spectrum sharing.

Future research should focus on improving event detection and localization to minimize false positives and negatives, as well as refining dynamic coexistence mechanisms. Additional empirical studies on path-loss models in real-world environments will improve the accuracy of interference assessments. Through careful planning and advanced detection and regulatory mechanisms, sharing spectrum with BAS can effectively address spectrum scarcity and promote innovation in wireless communications.

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References

[1] The Federal Communications Commission, “Expanding use of the 12.7-13.25 GHz band for mobile broadband or other expanded use,” *Notice of Inquiry*, October 27, 2022.

[2] The Federal Communications Commission, "Unlicensed use of the 6 ghz band; and expanding flexible use in mid-band spectrum between 3.7 and 24 ghz," *Proposed Rule*, February 26 2024.

[3] M. Ghosh, "Evolution of sharing in 6 GHz," *IEEE Wireless Communications*, October 2023.

[4] A. Davidson, "National spectrum strategy implementation plan," *National Telecommunications and Information Administration (NTIA)*, March 12, 2024.

[5] G. Cavell, *National Association of Broadcasters Engineering Handbook*. Routledge, 11 ed., 2017.

[6] E. Ostrom, *Governing the Commons: The Evolution of Institutions for Collective Action*. Cambridge University Press, 1990.

[7] E. Schlager and E. Ostrom, "Property-rights regimes and natural resources: A conceptual analysis," *Land Economics*, 1992.

[8] National Spectrum Management Association, "Fixed service frequency coordination in the broadcast auxiliary service and cable television relay service bands of 6875–7125 MHz and 12700–13150 MHz," *Recommendation WG 03.17.001*, https://www.nsma.org/recommendations/.

[9] The Federal Communications Commission - Technology Advisory Council, "A preliminary view of spectrum bands in the 7.125 - 24 GHz range; and a summary of spectrum sharing frameworks," *Advanced Spectrum Sharing Working Group*, August 17, 2023.

[10] U. Anjum, V. Zadorozhny, and P. Krishnamurthy, "Localization of unidentified events with raw microblogging data," *Online Social Networks and Media*, vol. 29, May 2022.

[11] R. H. Coase, "The federal communications commission," *Journal of Law Economics*, 1959.

[12] L. Herzel, "My 1951 color television article," *The Journal of Law and Economics*, vol. 41, no. S2, pp. 523–528, 1998.

[13] T. W. Hazlett, *The Political Spectrum: The Tumultuous Liberation of Wireless Technology, from Herbert Hoover to the Smartphone*. Yale University Press, 2017.

[14] G. H. Douglas, *The Early Days of Radio Broadcasting*. McFarland and Company, 1987.

[15] P. W. Huber, *Law and Disorder in Cyberspace: Abolish the FCC and Let Common Law Rule the Telecosm*. Oxford University Press, 1997.

[16] T. W. Hazlett, "Optimal abolition of fcc spectrum allocation.," *Journal of Economic Perspectives*, vol. 22, no. 1, pp. 103–128, 2008.

[17] The Federal Communications Commission, "FCC fact sheet: The commission begins the process for authorizing 6 ghz band automated frequency coordination systems," *Public Notice – ET Docket No. 21-352*, September 9, 2021.

[18] European Conference of Postal and Telecommunications Administrations, "Winner ii channel models," *https://www.cept.org/files/8339/winner -final report.pdf*, 2007.

[19] "Open afc - telecom infra project," May 2024.

[20] NTIA Office of Spectrum Management, "...permissible changes to the aggregate interference model that spectrum access system (SAS) administrators use to protect federal operations in the 3.55-3.7 GHz (3.5 GHz) band from citizens broadband radio service (CBRS) users"," *Notice to the FCC*, June 11 2024.

[21] A. Roivainen, P. K. sti, V. Hovinen, C. F. Dias, N. Tervo, M. Sonkki, G. Fraidenraich, and M. Latva-aho, "Validation of deterministic radio channel model by 10 GHz microcell measurements," *European Wireless*, 2016.

[22] N. Yoza-Mitsuishi, C. Anderson, and P. Mathys, "Propagation model analysis for 7- and 13-GHz spectrum sharing in urban environments," *IEEE Wireless Communication Letters*, 2022.

[23] N. Yoza-Mitsuishi and R. Sun, "Path loss characterization of 7-GHz terrestrial propagation channel in urban environment," *90th IEEE Vehicular Technology Conference*, 2019.

[24] DVB Bluebook, "Digital video broadcasting (DVB); framing structure, channel coding and modulation for digital terrestrial television (DVB-T)," *DVB Document A012*, June 2015.

[25] Ofcom, UK's Communications Regulator, "Hybrid sharing: enabling both licensed mobile and wi-fi users to access the upper 6 GHz band," *Consultation*, July 2023.

[26] Ofcom, UK's Communications Regulator, "Mobile and wi-fi in upper 6 GHz: Why hybrid sharing matters," *Available at: https://www.ofcom.org.uk/__data/assets/pdf_file/0023/285710/mobile-and-wi-fi-in-upper-6-ghz.pdf*, May 21, 2024.

[27] A. Sahoo, N. E. Ouni, and V. Shenoy, "A study of timing constraints and SAS overload of SAS-CBSD protocol in the CBRS band," *IEEE Globecom Workshops*, 2019.

[28] C. Song, M. A. Rahman, and H. Harada, "New robust sensing methods for DVB-T signals," *CrownCom*, 2011.

[29] J. Chuang, L. J. Cimini, and N. S. and, "Chapter 13 - wideband wireless packet data access," in *Multimedia Communications* (J. D. Gibson, ed.), Communications, Networking and Multimedia, pp. 221–246, San Diego: Academic Press, 2001.

[30] http://broadcastengineering.com/eng/sprint-nextel-completes-2ghz-bas-relocation 20100728/, "Sprint nextel completes 2GHz BAS relocation project," *Wayback Machine Internet Archive*, 2010.

[31] P. Bustamante, M. Gomez, W. Lehr, I. Murtazashvili, A. Palida, and M. B. Weiss, "Examining the us amateur-radio community through a polycentricity lens," *Telecommunications Policy*, vol. 47, no. 10, p. 102667, 2023.

[32] D. Blackwater, I. Murtazashvili, and M. Weiss, "Spectrum sovereignty on tribal lands: Assessing the DIGITAL reservations act," *Journal of Information Policy.*, 2023.

[33] D. Blackwater, I. Murtazashvili, and M. Weiss, “Polycentric systems for spectrum management: The case of indigenous spectrum sovereignty movements.,” *European Journal of Law and Economics*, 2024.

[34] P. Bustamante, M. Gomez, P. Krishnamurthy, W. Lehr, I. Murtazashvili, A. Palida, and M. B. Weiss., “Unassigned spectrum: An institutional analysis of radio spectrum management,” *Telecommunications Policy Research Conference*, 2023.

[35] L. Polak, D. Plaisner, O. Kaller, and T. Kratochvil, “Influence of LTE uplink system on DVB-T system at different coexistence scenarios,” *38th International Conference on Telecommunications and Signal Processing*, 2015.

[36] A. Tekovic, G. Šimac, and K. Šakiü, “LTE downlink system performance measurement with intersystem interference caused by DVB-T signal,” *54th International Symposium ELMAR*, 2012.

[37] K. Pelechrinis, G. Yan, S. Eidenbenz, and S. Krishnamurthy, “Detection of selfish manipulation of carrier sensing in 802.11 networks,” *IEEE Transactions on Mobile Computing*, vol. 11, July 2012.

[38] P. Bustamante, M. Gomez, I. Murtazashvili, and M. Weiss, “Spectrum anarchy: why self-governance of the radio spectrum works better than we think,” *Journal of Institutional Economics*, vol. 16, no. 6, 2020.

[39] C. Wardle and A. Williams, “Beyond user-generated content: a production study examining the ways in which ugc is used at the bbc,” *Media, Culture & Society*, vol. 32, no. 5, pp. 781–799, 2010.

[40] S. Dogan-Tusha, M. I. Rochman, A. Tusha, H. Nasiri, J. Helzerman, and M. Ghosh, “Evaluating the interference potential in 6 GHz: An extensive measurement campaign of a dense indoor Wi-Fi 6E network,” *WiNTECH ’23: Proceedings of the 17th ACM Workshop on Wireless Network Testbeds, Experimental evaluation Characterization*, 2023.