Out-of-Band Interference Management to Protect Radio Astronomy

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***Abstract*—Radio astronomy has revolutionized our understanding of the cosmos by detecting and analyzing weak radio emissions from celestial sources using highly sensitive instruments. The rapid expansion of 5G networks near these passive radio applications poses a substantial risk of out-of-band interference, potentially violating their stringent interference thresholds and compromising the integrity of astronomical observations. This paper explores methodologies to effectively manage out-of-band interference from 5G base stations (BSs) to radio astronomy sites. We design a novel power control algorithm to maximize both the number of active BSs and their transmit powers while ensuring the interference threshold at the radio astronomy site is not violated. We compare it with state-of-the-art approaches: Radio Quite Zone (RQZ) and move list. Through simulation experiments on real-world VLBA, we demonstrate that the power control algorithm achieves the smallest number of deactivated BSs by utilizing a lower power level. However, the move list algorithm achieves the smallest uncovered region by using the maximum transmit power. Both the power control and the move list algorithms significantly outperform the RQZ in terms of the number of active BSs and coverage.**

***Index Terms*—Radio astronomy, interference management, out-of-band, 5G, power control**

I. Introduction

The FCC has recently introduced a new spectrum-sharing framework for the 4940–4990 MHz (4.9 GHz) band to facilitate the coexistence between public safety and non-public safety users [1]. This spectrum-sharing framework is managed by a nationwide entity, known as the *Band Manager* [2]. The primary function of the Band Manager is to coordinate access to the 4.9 GHz band for non-public safety users, such as 5G users while ensuring that they do not interfere with the critical operations of public safety users within the same band [2].

However, the deployment of 5G in the 4940–4990 MHz band poses a significant risk of *out-of-band interference* on the radio astronomy telescopes operating in the immediately adjacent 4990–5000 MHz band [3]. These telescopes employ extremely sensitive antennas capable of detecting cosmic signals as faint as 10^{-20} W, making them highly vulnerable to *both* in-band and out-of-band interference. Per ITU-RA.769 standards [3], the spectral power flux density arriving at Very Long Baseline Array (VLBA) in the 4990–5000 MHz band must remain below -200 dB(W/(m^2·Hz)). Therefore, it is crucial for the Band Manager to also consider and manage *out-of-band* interference from 5G operations in the 4.9 GHz band to VLBA [2].

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Problem Statement The key question we want to address is: *How to manage the powers of 5G BSs in the 4940–4990 MHz band to ensure their out-of-band interference complies with the interference thresholds in the 4990–5000 MHz band for radio astronomy?* Addressing this new and complex problem is challenging, as prior research has primarily focused on in-band interference, leaving out-of-band interference management less explored. For out-of-band interference management, we aim to minimize the impact on the 5G BSs in the 4.9 GHz band by: (i) minimizing the number of BSs that must cease transmission; (ii) for the active BSs, we aim to maximize their transmit powers in a fair manner.

State-of-the-Art and Limitations Although there are no existing studies specifically addressing the challenge of out-of-band interference from 5G BSs in the 4.9 GHz band on radio astronomy antennas, there are established interference protection approaches, such as the Radio Quiet Zone (RQZ) [4] and move list [5], [6].

RQZs are designed to create protected areas around sensitive facilities, such as radio astronomy sites, where no transmissions are allowed. These zones aim to reduce both in-band and out-of-band interference by establishing a buffer zone free of any significant signal sources. A prominent example is the National Radio Quiet Zone (NRQZ), which protects the Green Bank Observatory [4]. While effective at preventing interference, RQZs could be conservative, relying on worst-case assumptions that lead to the under-utilization of the radio spectrum.

In contrast, the move list approach, originally implemented in the CBRS band to protect Navy radars, provides a more dynamic strategy for managing interference. This approach involves generating a list of secondary users' BSs located near the incumbent users that must cease transmission when the incumbent users become active. While the move list concept is capable of addressing both in-band and out-of-band interference, it is primarily used to manage in-band interference in the CBRS band [5], [6]. This methodology is now being proposed for adaptation to protect radio astronomy telescopes during their operational periods [4]. However, the move list approach is determined based on fixed power levels, which do not fully take advantage of power control capabilities.

Our Contributions In this paper, we address the pressing but largely unexplored problem of out-of-band interference on radio astronomy telescopes. We introduce a power control algorithm to manage out-of-band interference and compare its performance with RQZ and move list approaches. The main contributions of this paper are as follows:

- The power control algorithm aims to deactivate the minimum set of BSs to meet interference constraints. It then optimizes the transmit power level of the remaining active BSs, ensuring fairness across these BS by following the lexicographic maximization (LM) concept.
- We prove that under the LM power control approach, all active base stations in an optimal solution operate at the same power levels.
- Based on our findings on LM power control, we design the power control algorithm by maximizing the power levels while meeting the interference thresholds on radio astronomy antennas.
- Through numerical results on a real-world radio astronomy site, we show the inherent trade-offs between our power control and move list solutions, both of which significantly outperform the RQZ solution.

II. Modelling and Objective

In this section, we mathematically model the out-of-band interference protection constraint required by the VLBA. Subsequently, we discuss an LM-based objective that aims to achieve a fair maximization of all the base station power levels.

A. Interference protection for the VLBA

We first mathematically characterize the out-of-band interference at the radio astronomy antenna. Denote the aggregate spectral power flux density incident at the radio astronomy antenna as S_H (expressed in dB(W/(m^2·Hz))), which is formulated as follows [7]:

$$S_H = 10\cdot\log_{10}\left(0.1\cdot\sqrt{\frac{W}{t}}\cdot\sum_{b\in\mathcal{B}} I_b(p_b)\right) + K - 10\cdot\log_{10} W \quad (1)$$

where W represents the bandwidth of operation in Hz for a radio astronomy antenna, t denotes the integration time (the amount of time over which the observation data is collected at the VLBA) in seconds, $\mathcal{B}$ is the set of base stations that can generate interference to the VLBA, $I_b(p_b)$ denotes the received adjacent band interference (power spectral density) in W/Hz from base station b operating at power p_b, and $K = 20\cdot\log_{10} f - 158.5$ dB(m^2· Hz), with f being the center frequency in Hz. For the band spanning 4990–5000 MHz, we have $W =$ 10 MHz and $f = 4995$ MHz. The default value for t is 2000s. The determination of $I_b(p_b)$ will be presented in Section IV-B.

To protect the VLBA when it is active, the total adjacent band interference at the VLBA should not exceed the threshold of $T = -200$ dB(W/(m^2·Hz)) [7]. Thus, we establish the following interference protection constraint:

$$10\cdot\log_{10}\left(0.1\cdot\sqrt{\frac{W}{t}}\cdot\sum_{b\in\mathcal{B}} I_b(p_b)\right) + K - 10\cdot\log_{10} W \le T \quad (2)$$

B. Lexicographic maximization for base station powers

We assume that a base station b can adjust its transmit power level p_b within a range $[p_{\min}, p_{\max}]$, where $p_{\min}$ and $p_{\max}$ denote the minimum and maximum power levels determined by its hardware, respectively. Each base station b aims to maximize its p_b value so that it can provide good quality of service to its end users. On the other hand, these base stations need to meet the interference protection constraint (2).

A key design consideration in this context is fairness. Simply maximizing the total power, i.e. $\max \sum_{b\in\mathcal{B}} p_b$, is not a suitable objective, as it may result in some base stations operating at much higher power levels than others. Consequently, one might consider the max-min objective, i.e., $\max \min_{b\in\mathcal{B}} p_b$, which aims to ensure fairness by maximizing the minimum power level across all base stations. However, this objective does not seek to maximize the power levels of those base stations that can operate at power levels higher than $\min_{b\in\mathcal{B}} p_b$. To address these limitations, we apply the LM concept in this paper to achieve fairness while maximizing the power levels of all the base stations. We first define how to compare any two solutions under the LM criteria as follows.

Definition 1. *For a solution ψ with a sorted power vector $\mathbf{p} = [p_1, p_2, \cdots, p_B]$ and another solution $\hat{\psi}$ with a different sorted power vector $\hat{\mathbf{p}} = [\hat{p}_1, \hat{p}_2, \cdots, \hat{p}_B]$, where B is the number of base stations, $p_1 \le p_2 \le \cdots \le p_B$, and $\hat{p}_1 \le \hat{p}_2 \le \cdots \le \hat{p}_B$, ψ is better than $\hat{\psi}$ (or $\mathbf{p}$ is better than $\hat{\mathbf{p}}$) under the LM criteria if and only if there exists a k, $1 \le k \le B$, such that $p_b = \hat{p}_b$ for $1 \le b \le k-1$ and $p_k > \hat{p}_k$.*

Under the LM criteria, the objective is to iteratively maximize the transmit power across all base stations. The optimization process first maximizes the power for all base stations until a subset of base stations reaches a point where further power increases are not possible. Subsequently, the optimization shifts to maximizing the power of the remaining base stations until the next subset reaches its limit. This iterative process is repeated until no further power increase can be achieved for any base station. We formally define the LM optimal solution as follows.

Definition 2. *A solution ψ^* with a sorted power vector $\mathbf{p}^*$ is an LM optimal solution if and only if there is no solution $\hat{\psi}$ with a sorted power vector $\hat{\mathbf{p}}$ such that $\hat{\mathbf{p}}$ is better than $\mathbf{p}^*$ under Definition 1.*

III. Analysis and Optimal Algorithm

In this section, we analyze the LM optimal power control problem and derive an optimality condition. Based on this insight, we develop an optimal algorithm to address the power control challenges effectively.

A. Analysis on the LM optimal power control problem

In this section, we analyze the LM optimal power control problem to obtain some insights that can be explored to design an optimal solution in Section III-B. Our analysis begins by identifying a set of base stations that must be turned off in any solution. Specifically, if the interference generated by a base station at its minimum power level, p_{min}, exceeds the threshold, that base station must be turned off when the VLBA is active. We define this set of base stations as:

$$\mathcal{B}_0 = \{b : 10 \cdot \log_{10}\left(0.1 \cdot \sqrt{\frac{W}{t}} \cdot I_b(p_{min})\right) + K - 10 \cdot \log_{10} W > T, b \in \mathcal{B}\} .$$

In Section IV, we will show that this set is not empty. This observation further validates our selection of the LM objective over the max-min objective, as the latter tends to produce trivial solutions where $\min_{b \in \mathcal{B}} p_b = 0$. Further, in the design of our algorithm, base stations in $\mathcal{B}_0$ can be excluded from consideration. This exclusion reduces the problem size and algorithm complexity.

Note that $\mathcal{B}_0$ does not correspond to a quiet zone. The concept of a quiet zone allows any base station outside the designated area to transmit without violating interference protection requirements. In contrast, base stations in $\mathcal{B}_0$ are typically situated in a very small region near the VLBA. If all the base stations that are not in $\mathcal{B}_0$ are transmitting, the interference protection requirement may not be met.

We then prove an optimality condition concerning the power levels of active base stations in the optimal solution.

Lemma 1. *In an LM optimal power control solution, all active base stations must have the same power.*

Proof. We prove this lemma by contradiction. Assume that there exists an LM optimal solution ψ^* in which the active base stations operate at different power levels. We build a sorted power vector for all base station power levels. Suppose the minimum of these power levels is p, which is used by base station b. If multiple base stations operate at power level p, we select b as the base station corresponding to the last occurrence of p in the sorted power vector.

Based on our assumption on ψ^*, there exist some active base stations with power levels greater than p. Suppose base station d operates at a power level q, where $q > p$. If multiple base stations use the power level q, then we select d as the base station corresponding to the first occurrence of q in the sorted power vector.

We now show how to obtain a new solution $\hat{\psi}$ with a better-sorted power vector and obtain a contradiction. We slightly reduce the power of base station d to $\hat{q}$ such that its ranking in the sorted power vector remains unchanged. This reduction in d's power results in a decrease in aggregate interference at the VLBA. Thus, we can slightly increase the power of base station b to $\hat{p}$ such that

(i) the interference protection requirement (2) is satisfied and
(ii) its ranking in the sorted power vector remains unchanged.

Comparing the two solutions, since the power levels preceding $\hat{p}$ in solution $\hat{\psi}$'s sorted power vector are the same as those power levels preceding p in solution ψ^*'s sorted power vector and $\hat{p} > p$, solution $\hat{\psi}$ is better than ψ^* by Definition 1. According to Definition 2, this implies that ψ^* cannot be the LM-optimal solution, which leads to a contradiction of our initial assumption. Therefore, all active base stations must operate at the same power level in an LM-optimal solution. □

Algorithm 1 Identify base stations to be turned off

Input: $\hat{\mathcal{B}}$, T
Output: The set of turned off base stations $\mathcal{B}_1$
Set $p_b = p_{\min}$ for all $b \in \hat{\mathcal{B}}$
repeat
    Calculate S_H using Eq. (1) over set $\hat{\mathcal{B}}$
    if $S_H > T$ **then**
        Identify base station $b \in \hat{\mathcal{B}}$ with the highest interference value $I_b(p_b)$
        Set $p_b = 0$ and add b to $\mathcal{B}_1$
    end if
until $S_H \leq T$

B. Power Control Algorithm

We now proceed to develop the optimal power control algorithm. Recall that $\mathcal{B}$ is the set of base stations that can generate interference to the VLBA and $\mathcal{B}_0$ is the set of base stations whose individual interference exceeds the threshold when the VLBA is active. Denote $\hat{\mathcal{B}} = \mathcal{B} - \mathcal{B}_0$ as the set of base stations for which our power control algorithm will determine the power levels according to the LM criteria. Denote $\mathcal{B}_1$ as the set of base stations assigned zero power by the power control algorithm. Based on Lemma 1, the power control algorithm needs to determine

(i) the minimum set $\mathcal{B}_1$ of base stations to be turned off (if any) and
(ii) the maximum power level for the remaining base stations.

For (i), the power control algorithm initially assumes that all base stations $b \in \hat{\mathcal{B}}$ operate at the minimum power level, $p_{\min}$. Following this, it calculates the aggregate interference using equation (1) and verifies whether it meets the threshold T. If this aggregate interference violates the interference threshold, then the base station with the highest interference from the set $\hat{\mathcal{B}}$ is turned off, i.e., set its power level as 0 W and add it to $\mathcal{B}_1$. Then the power control algorithm calculates the aggregate interference again and verifies whether it meets the threshold T. If not, then the base station with the highest interference is turned off. This iterative process continues until the aggregate interference from the remaining base stations meets the threshold. This procedure is encapsulated in Algorithm 1.

For (ii), given that all active base stations use the same power level (Lemma 1), the power control algorithm initially checks if the power levels of these base stations can be set to $p_{\max}$ without violating the interference protection requirement. If this condition is not met, the algorithm simultaneously reduces the power levels of all the active base stations using a binary search[1] to find the maximum feasible power level that

[1]Note that $I_b(p)$ is a very complex function due to the inherent nonlinearities in MATLAB's calculation process, which will be described in detail in section IV-B. Due to these complex $I_b(p)$ functions, a binary search is necessary to find the maximum power.

Algorithm 2 Power control

Input: $\hat{\mathcal{B}}$, $\mathcal{B}_1$, T
Output: Power levels of each $b \in \hat{\mathcal{B}} \setminus \mathcal{B}_1$
For all $b \in \mathcal{B}_1$, set $p_b := 0$
For all $b \in \hat{\mathcal{B}} - \mathcal{B}_1$, set $p_b := p_{\max}$
Calculate S_H using (1) over set $\hat{\mathcal{B}}$
if $S_H \leq T$ **then**
    $p_b := p_{\max}$ for all $b \in \hat{\mathcal{B}} \setminus \mathcal{B}_1$
else
    Use binary search to find the highest p for all $b \in \hat{\mathcal{B}} \setminus \mathcal{B}_1$ that satisfies (2).
end if

satisfies the interference threshold. A detailed description of the power control algorithm is provided in Algorithm 2.

IV. Numerical Results

In this section, we demonstrate the performance of the power control algorithm for a real-world scenario involving a radio astronomy site and 5G base station deployment. We show that

- The power control algorithm meets the interference protection requirement on the radio astronomy site.
- While the power control algorithm deactivates the minimum number of base stations, it involves a trade-off between network utilization and coverage (power level).

We use MATLAB 2022b for simulating all experimental scenarios. The base station locations and KML files are generated using QGIS version 3.30.0-'s-Hertogenbosch [8].

A. Topology and parameter setting

We consider the VLBA radio astronomy site located in Hancock within Hillsborough County, New Hampshire, USA. The geographical coordinate of the telescope in Decimal Degrees (DD) is $\{42.9333, -71.9833\}$ [9] and is marked with the blue pin in Fig. 1. Further, we assume that a disk with a 2-mile radius around the VLBA (shown in red in Fig. 1) is occupied by the VLBA site. The VLBA radio astronomy antenna is positioned at a height of 30 meters [10] and has 0 dBi gain [3], [11].

For the adjacent band interference, we consider 5G base stations operating within a 50 MHz channel in the 4.9 GHz band. We deploy 5G base stations around the 2-mile radius VLBA site on a grid of 3×3 miles over a disk with a 25-mile radius (shown in blue in Fig. 1). There are a total of 273 base stations. For all 5G base stations, we assume that they can use any power level in [5, 62] dBm/MHz [12], and heights are randomly assigned in [25, 50] m [13].

B. Out-of-band interference calculation

To assess the interference within the 4990–5000 MHz band caused by transmissions from 5G base stations operating on a 50 MHz channel in the 4.9 GHz band, we first determine the adjacent channel power. We then subtract the path loss value from this adjacent channel power.

Fig. 1: VLBA radio astronomy site in Hillsborough County, NH, USA

We simulate an Orthogonal Frequency Division Multiplexing (OFDM) signal to determine the adjacent channel power using 5G numerology 0 for each deployed base station. The simulation utilizes a subcarrier spacing of 15 kHz across 277 resource blocks, with each block containing 12 subcarriers. The configuration of the OFDM system includes a sampling rate of 100 MHz and a fast Fourier transform size of 4096. Additionally, the signal generation process involves modulating data with 64-QAM and using the inverse fast Fourier transform to construct the OFDM symbols. Finally, we apply a low-pass filter with a 25 MHz cutoff frequency and a filter order of 120, employing a Hamming window, to maintain the signal within the desired bandwidth.

Next, we determine the power leakage into the adjacent channel of the OFDM signal using MATLAB's comm.ACPR tool [14]. The MATLAB's comm.ACPR tool measures the Adjacent Channel Power Ratio (ACPR) of a signal by determining the power distribution between the main channel and its adjacent channels. The outputs from this measurement include the power levels in both the main and adjacent channels. An ACPR measurement system object has several parameters (properties). These include the Sampling Rate, Main Channel Measurement Bandwidth, Adjacent Measurement Bandwidth, and Adjacent Channel Frequency Offset. The Main Channel Measurement Bandwidth specifies the bandwidth within which the object measures the main channel power. The Adjacent Measurement Bandwidth specifies the bandwidth used to measure the adjacent channel power. The Adjacent Channel Frequency Offset indicates the distance between the main channel center frequency and the adjacent channel center frequency. For our simulation experiment, we set the main measurement bandwidth at 50 MHz (4940–4990 MHZ), the adjacent measurement bandwidth at 10 MHz (4990–5000 MHz), and an adjacent channel offset of 30 MHz. After obtaining the adjacent channel power, we subtract the path loss values to estimate the adjacent band interference. The path loss calculations from each base station to the radio astronomy site are conducted using the Irregular Terrain Model (ITM) in point-to-point mode [11]. In the ITM, signal attenuation is quantified as a function of time, geographic location, and situational variabilities [15], [16]. We set these parameters to default values as specified in [11].

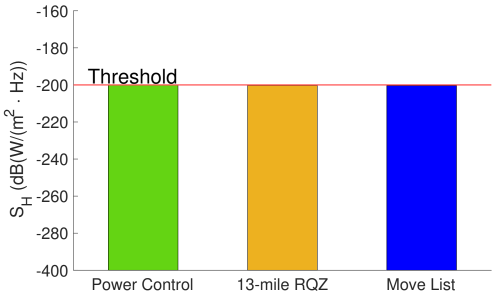


Fig. 2: Spectral power flux density received at VLBA under the three out-of-band interference management solutions.

C. Performance Evaluation

In this section, we obtain an optimal solution by the power control algorithm and then compare the performance of the power control algorithm with two benchmark approaches. Note that both benchmark approaches use a fixed power p_{max}, while the power control algorithm can reduce power to activate more base stations.

- Radio Quiet Zone (RQZ): RQZs are implemented to minimize potential interference with radio astronomy. It defines a geographic quiet zone around the VLBA, where no transmitters are allowed. Due to a lack of specification on the size of the quiet zone, we evaluate various sizes of quiet zones to determine the smallest size that satisfies the interference threshold T.
- Move List: The move list is a list of base stations that must be turned off to satisfy the interference threshold at the VLBA. To determine the move list, we use Algorithm 1, with two modifications: (i) the input set is $\mathcal{B}$ and (ii) setting $p_b = p_{\max}$ at line 3 of the algorithm.

First, we verify whether each algorithm meets the interference threshold requirement for the VLBA. Fig. 2 shows the spectral power flux density (interference) received at the VLBA antenna from the solutions obtained via the power control algorithm, 13-mile RQZ[2], and move list algorithms. Note that the radius of the RQZ is determined by trying different values for the deployed base stations, and setting it to the smallest value that meets the interference threshold. The spectral power flux density received at the VLBA antenna from the solutions obtained via the power control algorithm is -200.4 dB(W/(m^2·Hz)), 13-mile RQZ is -200.3 dB(W/(m^2·Hz)), and move list is -200.1 dB(W/(m^2·Hz)). Clearly, all the algorithms meet the interference threshold of $T = -200$ dB(W/(m^2·Hz)).

Table I presents a comparison of the power control algorithm, the 13-mile RQZ, and the move list. In this deployment, the set $\mathcal{B}_0$—representing base stations that must be deactivated to meet interference constraints—consists of 9 base stations. Beyond this, the power control algorithm deactivates an additional 14 base stations, whereas the 13-mile RQZ and move list algorithms deactivate 78 and 23 additional base stations, respectively. That is, the 13-mile RQZ and move list algorithms deactivate 457.1% and 64.3% more base stations than the power control algorithm, respectively. Figure 3 illustrates the distribution of active and deactivated base stations for all three algorithms, where active base stations are marked with green "·" symbols and deactivated base stations with red "·" symbols. It is important to note that the move list algorithm deactivates some base stations located farther from the VLBA. This behavior is due to the ITM channel model that captures terrain and other factors, which result in greater interference impact over longer distances.

[2]By "13-mile RQZ," we refer to a Radio Quiet Zone that is a circular disk with a 13-mile radius. This format will be used to specify the size of the RQZ throughout the remainder of this section.

TABLE I: Comparison of Three Out-of-Band Interference Management Solutions.

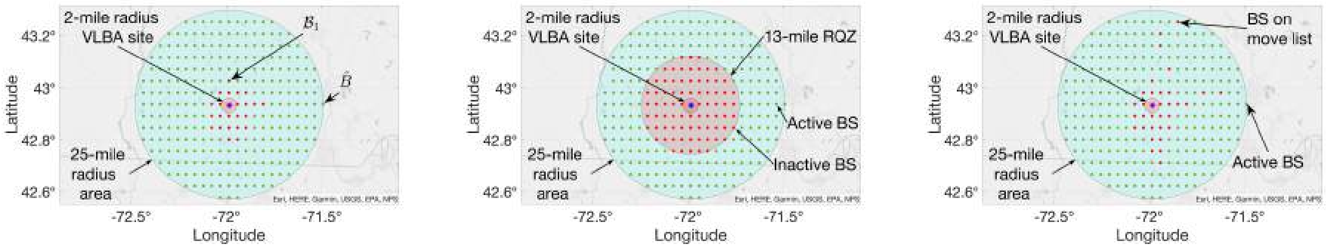
Solutions	# of turned-off BS (out of a total of 273 BSs)	p (dBm/MHz)	Total area without coverage (sq miles)
Power Control	14	58	37.7
13-mile RQZ	78	62	296.2
Move List	23	62	14.6

This reduction in deactivated base stations for the power control algorithm is achieved by operating the active base stations at a lower power level of 58 dBm/MHz, compared to the 62 dBm/MHz power level used in the 13-mile RQZ and move list solutions. While this lower power level allows the power control algorithm to keep more base stations active, it introduces a trade-off in terms of coverage. Table I, column 4, provides the total area (in square miles) left without coverage for each solution. The geographic distribution of these uncovered areas is shown in Fig. 4, where green areas represent regions with coverage, and yellow areas indicate regions without coverage. To estimate coverage, a contour level of -89 dBm [17] is used, with the path loss modeled using the formula $PL = 128.1{+}37.6{\cdot}\log_{10} d$ [18]. This model yields a coverage radius of 4.7 miles for base stations operating at 58 dBm/MHz and 6 miles for those operating at 62 dBm/MHz. Using QGIS, the total uncovered area was calculated as 37.7 mi^2 for the power control solution, 296.2 mi^2 for the 13-mile RQZ, and 14.6 mi^2 for the move list algorithm. Although the power control algorithm significantly reduces the number of deactivated base stations, it results in a larger uncovered area compared to the move list approach, due to the lower transmit power. This trade-off reflects the power control algorithm's strategy of allowing more base stations to remain active while accepting a slight reduction in overall coverage.

Finally, we examine the computational time required by the three algorithms: the power control algorithm takes 5 ms, RQZ takes 3 μs, and the move list takes 7 ms. All three algorithms exhibit very low computational complexity.

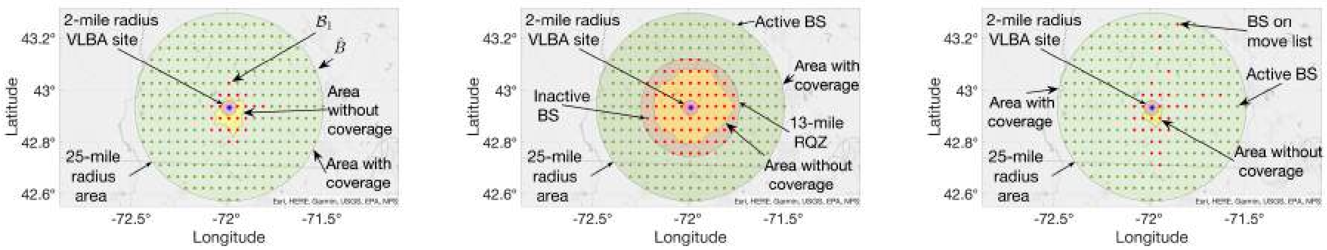
V. Conclusions

In this paper, we investigated the largely unexplored problem of out-of-band interference management for radio astronomy. We considered three possible approaches: power control, RQZ, and move list. For power control, we designed a novel and fair algorithm to maximize the number of active BSs



(a) Power Control (b) 13-mile RQZ (c) Move List

Fig. 3: Active and deactivated BSs under the three out-of-band interference management solutions.



(a) Power Control (b) 13-mile RQZ (c) Move List

Fig. 4: Coverage areas under the three out-of-band interference management solutions.

and their power levels while meeting out-of-band interference threshold for radio astronomy. We evaluated the performance of three solutions on a real-world VLBA deployment. We found that our proposed power control algorithm can offer the smallest number of turned-off BSs while the move list solution offers the best performance in terms of the coverage area. Both the power control and move list solutions significantly outperformed the RQZ approach in terms of the number of active BSs and area coverage.

References

[1] FCC, "4.9GHz: A Proposed Rule," May. 7, 2018. Available: https://www.federalregister.gov/documents/2018/05/07/2018-09416/49-ghz-band.

[2] FCC, "Seveth report and order and ninth further notice of proposed rulemaking," Jan. 18, 2023. Available: https://www.fcc.gov/document/fcc-updates-49-ghz-band-rules-seeks-further-comment.

[3] ITU, "Report ITU-R RA.2332-0: Compatibility and sharing studies between the radio astronomy service and IMT systems in the frequency bands 608-614 MHz, 1330-1400 MHz, 1400-1427 MHz, 1610.6-1613.8 MHz, 1660-1670 MHz, 2690-2700 MHz, 4800-4990 MHz and 4990-5000MHz." November, 2014. Available: https://www.itu.int/dms_pub/itu-r/opb/rep/R-REP-RA.2332-2014-PDF-E.pdf.

[4] Wireless Innovation Forum, "Passive and Active Spectrum Sharing (PASS)," Oct. 12, 2021. Available: https://winnf.memberclicks.net/assets/Proceedings/2021Virtual/Protection%20of%20Passive%20Services%20%20WInnComm%202021.pdf.

[5] WInnForum Spectrum Sharing Committee, "Spectrum Sharing Committee CBRS Incumbent Protections and Encumbrances Overview," Document WINNF-TR-5003, Version V1.0.0, Apr. 28, 2020. Available: https://winnf.memberclicks.net/assets/CBRS/WINNF-TR-5003.pdf.

[6] FCC, "3.5 GHz Band Overview," April 3, 2023. Available: https://www.fcc.gov/35-ghz-band-overview.

[7] ITU, "Recommendation ITU-R Ra.769-2: Protection criteria used for radio astronomical measurements." May 5, 2003. Available: https://www.itu.int/dms_pubrec/itu-r/rec/ra/R-REC-RA.769-2-200305-I!!PDF-E.pdf.

[8] QGIS, "Download QGIS for your platform," [Online]. Available: https://www.qgis.org/en/site/forusers/download.html. [Accessed: Sep 11, 2024].

[9] FCC, "FCC online table of frequency allocations," July 1, 2022. Available: https://transition.fcc.gov/oet/spectrum/table/fcctable.pdf.

[10] University of Hawaii - Institute for Astronomy, "Amendment to the Mauna Kea Science Reserve Complex Development Plan," Sept. 1988. Available: https://files.hawaii.gov/dbedt/erp/EA_EIS_Archive/1988-09-DD-HA-SFEIS-Mauna-Kea-Science-Reserve-Complex-Development-Plan.pdf.

[11] NTIA, "4990-5000 MHz," Sept. 1, 2014. Available: https://www.ntia.gov/files/ntia/publications/compendium/4990.00-5000.00_01SEP14.pdf.

[12] RTCA Inc., "Assessment of C-Band Mobile Telecommunications Interference Impact on Low Range Radar Altimeter Operations," Oct., 2020. Available: https://www.rtca.org/wp-content/uploads/2020/10/SC-239-5G-Interference-Assessment-Report_274-20-PMC-2073_accepted_changes.pdf.

[13] Faststream Technologies, "5G ORAN Base Station," 2023. Available: https://www.faststreamtech.com/products/5g-oran-base-station/#:~:text=It%20uses%20an%20antenna%20located,of%20devices%20while%20minimizing%20latency..

[14] The MathWorks Inc., "MATLAB Communications Toolbox," 2024. Available: https://www.mathworks.com/help/comm/ref/comm.acpr-system-object.html#bti6e78. [Accessed: Sep 11, 2024].

[15] P. McKenna and C Hammerschmidt, "Radio Propagation Models," Propagation Measurement Workshop, July 28, 2016. Available: https://its.ntia.gov/media/66385/propmeasworkshop3july282016.pdf.

[16] E. Dorcella, J. Richards, R. Sole, F. Najmy, A. Lundy, and P. McKenna, "3.5 GHz Exclusion Zone Analyses and Methodology," NTIA Report, June 2015. Available: https://its.ntia.gov/publications/details.aspx?pub=2805.

[17] WInnForum Spectrum Sharing Committee Work Group 1, "Requirements for Commercial Operation in the U.S. 3550-3700 MHz Citizens Broadband Radio Service Band," Document WINNF-TS-0112, Version V1.9.22, March 2024. Available: https://winnf.memberclicks.net/assets/CBRS/WINNF-TS-0112.pdf.

[18] 3GPP, TR 36.931, "Radio Frequency (RF) requirements for LTE Pico Node B, version 15.0.0.,," June 2018. Available: https://portal.3gpp.org/desktopmodules/Specifications/SpecificationDetails.aspx?specificationId=2589.