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Spectrum Sharing Policy for a Cooperative Brokering System

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***Abstract*—As use of the radio frequency spectrum continues to grow, risk of interference to passive RF systems becomes greater. A cooperative spectral broker is proposed to dynamically coordinate frequency allocations amongst devices, offering protection for incumbents without compromising their performance and providing opportunistic access to frequencies outside original assignments and allocations. Policy measures necessary to support systems of this nature are suggested, and a case study for identifying bands and applications that could benefit from such a system and policy is discussed.**

***Index Terms*—Dynamic spectrum access (DSA), spectrum sharing, spectrum policy, fifth-generation (5G), out-of-band interference.**

I. Introduction

Fifth-generation (5G) broadband offers powerful advances in connectivity by providing higher data rates, greater network capacity, and broader coverage for rural and disconnected areas. The increased bandwidth required to support these benefits has resulted in greater use of mid-band and millimeter wave spectrum, leading to congestion and fewer contiguous blocks of spectrum large enough to support the growing needs of current and future generations of broadband technologies. In the past, static allocation of spectrum has been sufficient in providing unencumbered operating environments. A tiered access approach has been employed in which primary services of a frequency band are given priority access while secondary services are subject to additional rules and stipulations crafted to mitigate potential interference. The efficiency of this approach is now being challenged by new broadband requirements, resulting in scenarios of disparate services residing in adjacent frequency bands. The recent auction of 24 GHz spectrum to 5G wireless services has created such a scenario and presents a notable risk to the passive radiometers that operate in the 23.6 – 24 GHz band allocated to passive services, including the Earth Exploration-Satellite Service (EESS). Unable to adjust in frequency, these radiometers are subject to interference from unwanted adjacent-band emissions, presenting potential for delayed and less accurate weather forecasts [1]. Fig. 1 shows a diagram of this setup, as presented by Seguin [2]. In a weather-related emergency, such degradation in forecasting capabilities may result in slowed evacuations and threat to human life.

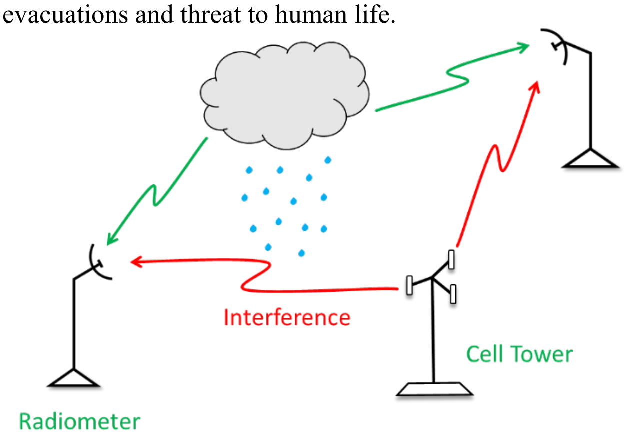

Fig. 1. Spectrum sharing scenario between passive radiometers and wireless communications. Reprinted from [2].

Dynamic spectrum access (DSA) can provide more efficient spectrum sharing than current static approaches. The need for static spectrum assignments is decreased by the ability to exploit available frequency bands outside original allocations, making future interference situations mitigable. Ahmad presents a survey on dynamic spectrum sharing techniques, categorizing them by architecture, behavior, and method of access [3]. Other works look more specifically at implementations of such systems, and provide algorithms demonstrating more efficient spectrum assignment, using aggregate interference tracking and standardized spectrum consumption models (SCMs) to capture intended spectrum use prior to an interference event [4-5]. Eichen presents a mechanism capable of coordinating real-time spectrum sharing amongst radiometers and 5G transmitters [6]. This Real-time Geographical Spectrum Sharing (RGSS) approach tracks the instantaneous field of view (IFOV) of the remote sensing satellite and takes appropriate action to mitigate interference sourced from within. Use of the radiometer's IFOV may make for difficulties extending RGSS to new sharing scenarios though.

There is no shortage of potential designs for DSA systems, but most works fail to bring into consideration the support such systems would require in practice. Two examples of spectrum coordination systems that have been deployed (or will be shortly) are the Spectrum Access System (SAS), used in the 3.5 GHz band for the Citizens Broadband Radio Service (CBRS) [7], and the Automated Frequency Coordination (AFC) system that will operate at 6 GHz [8]. These technologies differ from previous works mentioned in that their operations are governed by supporting policy frameworks codified into the Code of Federal Regulations, but the spectrum assignments carried out by either system are generally far from real-time, leaving them ill-equipped to handle scenarios requiring timely responses.

Another solution employing a similar notion is the spectral broker, which dynamically grants privileges to its users in the form of spatial-spectral masks [9]. This technique has also been developed specifically for the 24 GHz radiometer/5G coexistence scenario, where it has become evident that its speed and reconfigurability make it both extensible and scalable as a spectrum management solution. Like other approaches, the application of the spectral broker provides a new set of regulatory challenges in its implementation. Policy is needed that empowers the broker to carry out its function unimpeded. This paper introduces the spectral brokering system and state of the current regulatory environment, then proposes the policy innovations needed to support its operation at 24 GHz. Additionally, we explore select frequency bands that are anticipated to experience coexistence issues in the future and how the spectral broker, backed by a proper policy framework, can be applied.

II. Spectral Broker Approach

The cooperative brokering system coordinates spectrum use between active and passive users by considering spectral, spatial, and temporal resource use in its network and implementing constraints on potentially interfering devices. Fig. 2 shows the flow diagram for a spectral broker system as described by Seguin [2]. The broker functions by accepting operating requests from multiple radiometers and 5G systems, then undertakes a multi-stage culling process to determine interference potential between any pair of requests. If a device is identified as a potential interferer, a spatial-spectral mask is calculated considering the prioritization of passive devices and communicated to all users. The 5G transmitter's controller then has the opportunity to optimize beam pattern and reconfigurable power-amplifier (PA) matching networks to maximize resource use within the constraints provided by the broker [2].

The operating requests shared by users contain information regarding time of use, frequency and bandwidth, transmission power and receiver tolerance, and geographical location and directionality. With this information the broker begins assessing the most recently submitted request against existing allowances of other devices, covering all combinations of pairs. In each assessment, five stages of culling take place in which the broker evaluates overlap between parameters. The first three stages look for time overlap of the requests, whether the devices are within line of sight of each other, and whether the main beam of the transmitter's antenna pattern intersects the location of the other device. In stage four, free space loss calculations determine whether power of a transmission will exceed the interference tolerance of the receiving device. This stage considers only the interference power between any two devices and does not account for aggregate power from all interfering sources. The final stage performs frequency interference calculations by first looking for direct overlap between requested bands, then for out-of-band (OOB) interference potential. Each stage is dependent on the previous, meaning that at any point in the culling process, if no overlap is determined then the pair of devices under evaluation are found to present no potential interference to each other and the broker will proceed to the next pair, excluding following stages from its calculations. If all five stages of the culling process present interference potential, the broker will generate a spatial-spectral mask for the interferer that limits transmission power and

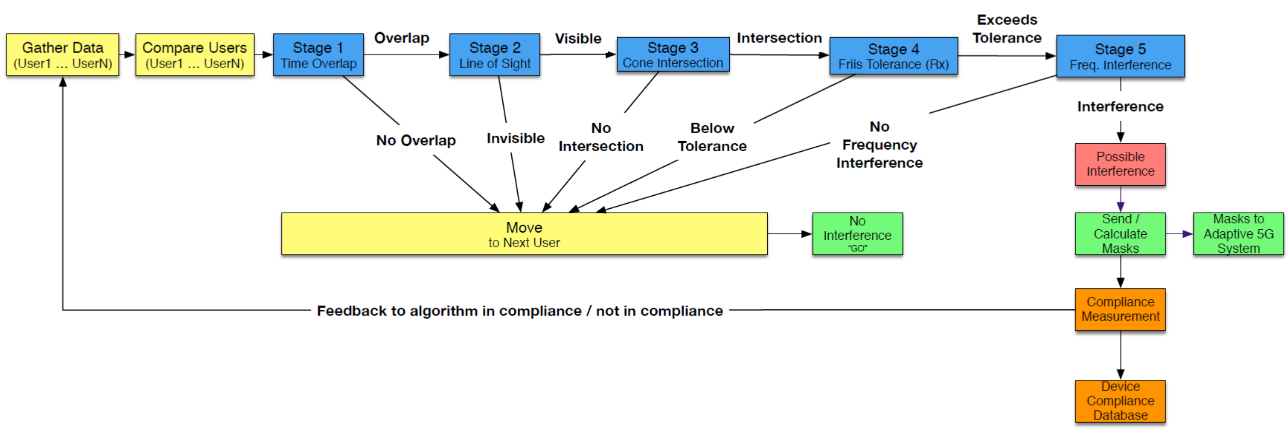

Fig. 2. Spectral broker process for weather radiometer coordination with wireless communications. Reprinted from [2].

direction as a function of frequency. These procedures are detailed more thoroughly in [2] and [9].

III. Policy in the 24 GHz Environment

At present, protections for the 23.6 – 24 GHz Earth Exploration-Satellite Service band within the United States are specified in footnotes US74, US211, and US246 of the Federal Communications Commission (FCC) allocation table [10]. These measures state no purposeful transmissions are allowed in the passive EESS band except by medical telemetry equipment and white space devices, but protections only apply in cases where offending stations are out of compliance with the technical standards of their service. The rules of the 23.6-24.0 GHz band are summarized in Table I. Limited power densities of emissions are specified for several active services surrounding the radiometers.

TABLE I
24 GHz Sharing Environment Summary

Active Service Frequency Band (GHz)	**Active Service**	**Limit on Unwanted Emissions**
22.55- 23.55	Inter-satellite	-36 dBW/200 MHz
24.25 - 24.45	Upper Microwave Flexible Use Service (UMFUS)	-20 dBW/200MHz
24.25 – 27.50	Mobile Service	Base stations: -33 dBW/200 MHz Mobile devices: -29 dBW/200 MHz

If interference to a passive device is detected but the offender is in compliance with its respective regulations, they are under no obligation to alter operation. Unwanted emissions are also considered, the International Telecommunication Union (ITU) has published OOB emission limits following the 2019 World Radiocommunication Conference (WRC-19) [11]. Resolution 750 of the WRC-19 final acts specifies the Total Radiated Power (TRP) limits of unwanted emissions within any 200 MHz in the 23.6 – 24 GHz passive band by International Mobile Telecommunications (IMT) base and mobile stations operating in 24.25 – 27.5 GHz, where the TRP is defined as the integral of the power transmitted from all antenna elements in different directions over the entire radiation sphere. For IMT base stations the TRP limit is -33 dBW/200MHz, set to decrease to -39 dBW/200MHz after September 1, 2027. IMT mobile stations are assigned less stringent limits, -29 dBW/200MHz currently and decreasing to -35 dBW/200MHz. Note that these limits have not been formally adopted in the United States but give an impression of what the future regulatory landscape will look like.

The process for establishing interference criteria is an important aspect of policy as well, and the ITU has a well-documented method of modeling IMT networks for coexistence studies used to inform such decisions. From [12], the ITU approach makes a variety of assumptions regarding the simulated IMT network such as antenna elevations, gain, and transmission angles as well as ground base station density and power levels. The simulation is also dependent on geographical area, a reference radiometer with operational characteristics defined by Recommendation ITU-R RS.1861 [13], and other ITU specifications on appropriate propagation models, user equipment (UE) power control, network loading, etc. To calculate the RF power detected by the reference radiometer, the sum of all power within the radiometer's bandwidth from all IMT network antennas is taken for the duration of one measurement time step. The total power at the radiometer must not exceed the noise equivalent power for 99.99% of all measurement time steps, each antenna's TRP is scaled until this criterion is met. This scaled TRP is then called the OOB emission limit.

Due to large numbers of base stations and UEs, sharing and compatibility studies are essential in the establishment of interference criteria, though determining emission limits neither too lenient nor too strict has proven difficult to achieve. Groups carrying out coexistence studies to inform decisions on interference criteria often do so with an agenda. The ITU's methodology for determining these criteria has been criticized by the FCC and US wireless carriers [14], arguing that ITU recommendations present a worst-case analysis. In contrast, many sharing and compatibility studies carried out prior to WRC-19 determined that more stringent limits than those published are necessary to mitigate interference in the passive EESS band, finding OOB emissions ≤ -40 dBW/200MHz necessary to ensure protection [15]. Additionally, these emission limits are static once implemented and can take four or more years to update (the length of the ITU regulatory cycle). Some have suggested the introduction of a third-party coexistence lab to conduct compatibility studies from a neutral position [16]. While this would alleviate some concerns regarding the establishment of appropriate interference criteria, it does little to support spectrum sharing applications with DSA systems. A modified approach to policy is needed to support the spectral broker. The same policy measures that support the broker can also help prevent discrepancies in interference criteria by determining them dynamically and on a case-by-case basis.

IV. Policy Innovation for Spectral Brokering

The scope of policy is dependent on the system it aims to govern. Implementation, maintenance, financing, security, and enforceability are all important aspects of a comprehensive framework capable of maintaining copacetic behavior amongst passive and active RF devices.

In this paper, focus is placed primarily on the spectral broker's operation. A supporting regulatory approach is organized into a framework with three distinct sections: (1) the brokering system itself, (2) RF devices in the brokered network, and (3) incumbent protections.

A. *Spectral Brokering System*

Policy measures provided to support the broker must give it explicit authority to dynamically manage spectrum but stipulate that it does so in a reliable and predictably biased or unbiased manner. Past difficulties in determining fair interference criteria have illustrated a need to provide special attention to choice of propagation model. Because radio access networks (RANs) may be distributed across a large geographical area, there is no one-size-fits-all model that can accurately represent every transmitter-receiver pair. Instead, choice of propagation model should depend on the specific nature of each link being established. This potentially requires multiple models to be used in the broker calculations but helps to ensure accurate representation of the radiometer-RAN network. We also consider the event in which an active device is unable to comply with its constraints for any reason. Broker access to the active devices and their operating standards will be critical to resolving conflicts where the device cannot bring itself into compliance. A set of policy measures capturing these foregoing topics are as follows:

1) Function: The brokering system shall determine spectral, spatial, and temporal allowances for devices registered within its network.

2) Priority of Assignments: The brokering system shall carry out calculations in a non-discriminatory manner unless incumbent operations are determined to be at risk.

3) Compliance Database: The brokering system shall maintain a secure database of past and present assignments, as well as a queue for future requests.

4) Propagation Model: Choice of propagation model for predicting interference between a transmitter and receiver should adhere to the most relevant ITU-R recommendations on radio propagation considering:

- Operating frequencies
- Antenna position and height
- Surrounding physical structures
- IMT deployment configuration, if applicable

5) Device Accessibility: The brokering system shall be provided access to devices and their operating standards to allow arbitration in instances of conflict due to non-compliance.

B. *Brokered Network Clients*

Similar to that discussed for the broker, policy regarding clients in a brokered network is also needed to capture the requirements of devices eligible for participation. Smooth operation depends on the devices, both passive and active, providing accurate information to the broker, complying with masks when assigned, and allowing the broker to bring them into compliance when necessary.

1) Accuracy: Devices shall provide accurate information required by the brokering system to complete its calculations.

2) Adaptability: Active devices must be capable of adapting to a spatial-spectral mask and do so when provided one.

3) Location Availability: Devices shall be capable of obtaining and sharing geolocation data provided by either an internal or external source.

4) Device Accessibility: A device shall allow the brokering system to dictate operations in the case that the device is identified as causing harmful interference.

C. *Incumbent Protections*

When considering incumbent protections, we would like to provide the same, if not better, level of protection offered by legacy policies. If unacceptable levels of interference consistently remain present after action by both the interfering device and broker, the interference criteria established prior to the implementation of the spectral broker may be used. Also categorized under incumbent protections is the broker's capability to provide opportunistic access to spectrum outside an active device's originally allocated band. This allows more efficient use of the spectrum while maintaining the primary status of the incumbents in the band.

1) Backwards Compatibility: Preceding policy measures shall be maintained where interference to incumbent services remains, despite action by the brokering system.

2) Opportunistic Access: Access to additional spectrum outside an active device's allocated band may be provided by the brokering system if it presents no conflict with incumbent services in the requested band. All incumbents retain priority when interference occurs, and the opportunistic device must vacate the band.

V. Extending to new Scenarios

Though the broker has been developed specifically for the 24 GHz radiometer/5G coexistence scenario, there are a number of cases in which the present design may be utilized under the guidance of its supporting policy framework. In an ongoing case study, three frequency bands have been identified as being at risk of coexistence issues in the near future. In each case, the ability of the broker to coordinate spectral and spatial resources in near real-time can be leveraged to address the anticipated interference situation.

A. *4.2 – 4.4 GHz*

Radar altimeters (RAs) operating at 4.2 – 4.4 GHz are used by civil aircraft when elevation is below approximately 5000 ft. These altimeters are the only sensors onboard civil aircraft providing direct measurement of the aircraft's terrain clearance, making them life-critical systems unable to tolerate failures. 5G operations in the nearby 3.7 – 3.98 GHz band introduce risk of harmful interference to the RA band that may result in crippled automated landing systems, false warning signals upon take-off or during approach that can distract flight crew, missed warning signals that may lead to a controlled flight into terrain scenario, and various other malfunctions resulting from erroneous RA readings [17]. This scenario presents a risk that has potential to result in loss of human life. As such, there is a need for a solution that can mitigate OOB interference to the RA band while maintaining network availability for wireless carriers.

Recent advancements in RA technology have been developed leveraging digital and analog filtering techniques to tolerate 5G C-band interference [18], but this does not guarantee future mobile broadband innovations will not introduce interference to other aircraft wireless systems. A future-proof solution that offers benefits to both parties is an implementation of the spectral broker that retains priority access for aeronautical radionavigation in the 4.2 – 4.4 GHz band, while providing opportunistic access to the nearby or same frequency space for active services.

The spectral broker can coordinate dynamically between 5G transmitters and aircraft if the transmitter location and flight path are known. Opportunistic access can be offered within the RA band when no aircraft are in the vicinity. Upon an impending approach or takeoff, the broker can adjust the opportunistic 5G transmitter operations to clear the region surrounding the flight path of interfering transmissions. RAs keep priority status, and 5G active devices are directed to handoff traffic or pause transmission for the duration of the aircraft's request.

B. 10 – 10.5 GHz

WRC-19 Resolution 245 calls for an assessment of the 10 – 10.5 GHz frequency band for potential allocation to IMT and emphasizes ensuring that there are no additional regulatory or technical constraints placed on primary services in adjacent frequency bands [19]. This band is currently occupied by the federal radiolocation service, while passive EESS occupies the adjacent 10.6 – 10.7 GHz band, making this scenario notably similar to coexistence issues for 24 GHz EESS and 5G systems. It is anticipated that the spectral broker will be capable of protecting the passive radiometers near 10 GHz in the same fashion as near 24 GHz. The regulatory needs are also similar: the broker needs the right to coordinate spectrum use and will be required to do so in a manner agreed upon by participants or relevant regulatory agency. The devices operating in the 10 – 10.5 GHz band should be required to adhere to the provided constraints. Ensuring protection for passive devices also requires use of interference criteria specific to the situation at hand, these criteria should be evaluated with the installation of new IMT stations.

C. 12.7 – 13.25 GHz

At the 2022 National Telecommunications and Information Administration (NTIA) Spectrum Policy Symposium, FCC chairwoman Jessica Rosenworcel announced the 12.7 – 13.25 GHz band would be examined for allocation to next-generation wireless applications. Presently, this band is allocated for terrestrial mobile services domestically. These incumbents will require protections if they are to coexist with potential new entrants. In the FCC's Notice of Inquiry (NOI), information was sought regarding coexistence methodologies and protection levels for incumbent services in adjacent bands [20]. If the broker were to be utilized in this scenario, it could eliminate the need to disrupt present allocations by dynamically managing spectrum use in near real-time, and could also offer protection to adjacent band services. With accurate location data and scenario-specific propagation models, mobile services can be coordinated amongst each other. Incumbents should be protected from increases in harmful interference levels, while network availability should be maintained for 5G and 6G devices.

VI. CONCLUSION

Policy suggestions have been developed to enable a cooperative spectral broker to dynamically coordinate spectrum use amongst RF devices. Derived from the needs of passive weather radiometers coexisting with active 5G devices at 24 GHz, the policy supports a potentially useful solution to ensure that both scientific and commercial users of this band can maximize their performance. A set of policy measures addressing the operation of the spectral broker and its clients has been provided, emphasizing retainment of incumbent protections and situation-specific network modeling to mitigate harmful interference. Using the same framework, the application of the broker has also been evaluated in additional spectrum sharing scenarios, where brokering may improve efficiency of spectrum use and protection against harmful interference.

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