Spectrum Sharing Brokers for Active and Passive Devices

Abstract—**Acute spectral crowding has multiple efforts centered on the better use of electromagnetic spectrumand expanding spectrum use into increasingly higher frequencies. With the imminent proliferation of Fifth Generation (5G) systems in the 24 GHz band, these devices could present interference from out-of-band emissions to space-based weather radiometers conducting passive measurements of water vapor thermal emissions in the neighboring 23.6-24 GHz band. There is a critical need to accommodate both passive and active device transmitters, such as 5G systems, and allow for these active systems to adjust their transmissions to avoid critical weather radiometer systems in the nearby band. A brokering system that accounts for both passive and active devices for spectrum allocations is discussed that has the potential to protect crucial passive devices from unwanted interference by accounting for both in-band and out-of- band electromagnetic emissions. Then using these data, a spatial-spectral mask is created that can be utilized by an active device user to avoid interference with the nearby passive devices.**

I. Introduction

Enhanced collaboration among all of the agencies that govern spectrum (e.g. FCC, NTIA, NOAA, and NASA) was demanded in a letter from the U.S. House of Representatives Committee on Science, Space, and Technology [1], outlining the critical needs to maintain sensing capabilities while still furthering 5G and other wireless development.

It has been noted that a 30 percent reduction in weather forecast accuracy is possible due to interference from 5G transmitters in the neighboring 24 GHz band, according to Neil Jacobs, Acting Chief of the National Oceanic and Atmospheric Administration (NOAA), hav-ing the effect of setting us back to 1980s-level forecast- ing abilities [2]. Interference to these critical radiometer systems could severely impact safety when reportingon major weather events such as tornadoes, hurricanes, or any severe weather event [2]. In addition, Lubar atthe Aerospace Corporation mentions that 5G transmitter interference could result in a delay of up to 3 to 6 hours in accuracy of a three-day forecast, placing thousands or more at a greater risk during a national weather disaster [3].

Exclusive spectrum use, even for critical applications, such as radars and radiometers is becoming increasingly rare due to an ever increasing demand for spectrum fueled by emerging and existing technology needs. It is important to create strategies that efficiently share precious spectrum resources. Emerging brokering systems have the potential to provide better granularity of spectrum sharing, more efficient spectrum utilization, and the ability to implement policies and priority operation for critical systems.

Existing brokering mechanisms for sharing spectrum have generally been more focused on the contractual, licensing, and bidding aspects of allocation of the electromagnetic spectrum [4]–[6]. Further examinations by Zulfiqar have focused analyses on brokering spectrum by allocating based on market demands [7]. In addition, prior works have also presented a scalable brokering system that includes passive and active devices, using a computationally effective method for culling and determining if devices are at a threat for interference [8]. Generally, existing spectrum sharing allocation strategies have only analyzed and distributed spectrum bandwidth allocations based on in-band and device reported spectrum radiation parameters, despite the fact that all electronics do have some unintended out-of-band and harmonic emissions. Better and more efficient spectrum sharing that avoids interference to critical systems will require an increasingly complex yet scalable analysisof not only reported in-band device transmission parameters, but also account for possible out-of-band and harmonic emissions.

A cooperative brokering system for passive and active devices will be discussed, considering both in-band and out-of-band emissions as well as the discussion of a calculation of a spatial spectral mask for use by a 5G system to avoid critical radiometer and other system interference. A simple diagram of possible interactions

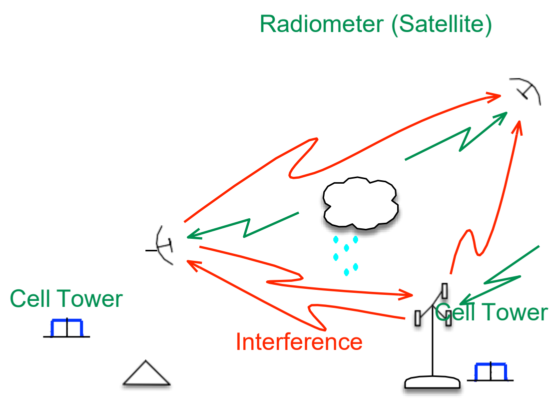

Fig. 1: Passive (radiometer) and active device interaction

TABLE I: Information Requested by the Broker from Each Device

Data Requested	Units
Date / Time	(24 hour time), start and stop time
Latitude	decimal degrees
Longitude	decimal degrees
Altitude	meters
Center Frequency	Hz
Bandwidth	Hz
Azimuth	degrees
Elevation	degrees
Transmitter Power	dBm
Receiver Power Tolerance	dBm
Antenna Gain	dBi
Time Interval Request	seconds

between a passive radiometer and an active 5G / communications system is shown in Fig. 1. Requeststo operate within a certain spectrum allocation from active and passive device users are sent to this broker. These requests include information about spectral, spa- tial, temporal, and device parameters, such as transmit power and receive power tolerance. The broker thenanalyzes all the information relayed from each device using a scalable culling process. This culling process does a calculation for spatial and temporal overlap, a possible power received calculation at affected devices, and calculations for potential out-of-band and harmonic radiated emissions that could interfere with vulnerable passive devices. Ultimately, the broker computes an adaptive spatial-spectral mask that is passed to the activedevice users, such as 5G systems, requesting access to the spectrum that considers out-of-band and in-band emissions and communicates if there is availability for transmissions based on all requesting active and passive devices, decreasing the likelihood of interference to other users of the spectrum.

II. Brokering the Spectrum for Sharing

Users of the electromagnetic spectrum have several parameters that dictate their specific spectrum needs. Specifically, these users have temporal, spatial, and spectral requirements. These requirements may be found in Table I and were originally gathered and presented in [8]. The broker presented here is a software program that accepts requests for spectrum usage that contains all of the information found in Table I if applicable (i.e. passive devices do not have a transmitter and, therefore, do not have a transmitter power) that is each device's manifold.

This broker then takes all of the information sent about each device that wishes to operate in the allotted spectrum and computes the intersections between all of these manifolds. It then returns a flag if it is permissible to proceed to transmit or receive applications, as well as calculates a spatial-spectral mask for active transmitters if it is determined that devices could interfere, considering the full device requirements as indicated by the device's manifold.

Fig 2 shows how the broker determines if there will be interference among any given set of devices. All requests and user manifolds are gathered by the broker and each request is evaluated in five stages of culling: Time Overlap, Line of Sight, Cone Intersection, Friis Tolerance, and a Frequency Interference Calculation. If the determined interference condition is met for the given stage, the device manifold comparisons continues to the next stage. If the interference condition is not met, then it is determined that those devices cannot interfere. All five stages of interference conditions must be met in order for interference to be possible. After it is determined that all five stage interference criteriaare met, then the broker flags those particular devicesfor interference, it then calculates a spatial-spectral maskthat specifies allowable transmissions and passes it to the active transmitting device. This broker gives preference to all passive devices.

A. Stages 1 – 3: Time Overlap, Line of Sight, and Cone Intersection

In stage 1 the broker first determines if there is any time overlap within the device manifolds, if not, then it is determined that there can be no interference. Following that, in Stage 2, it determines if any users are in the line of sight of each other on the Earth's Sphere [8]. Then in Stage 3, a Cone Intersection calculation is completed,

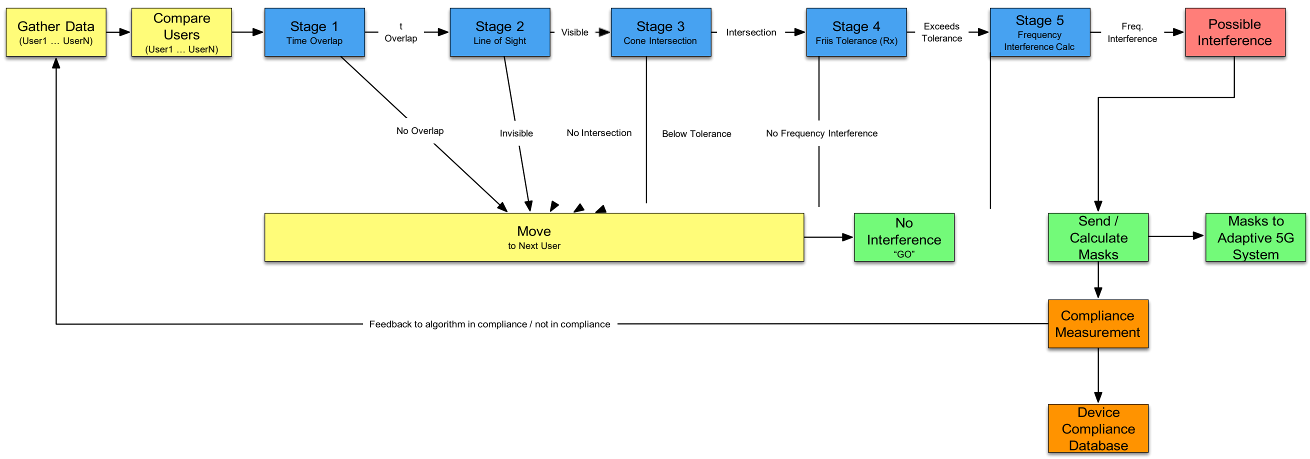

Fig. 2: A flow diagram showing an example brokering system used for multiple devices across the electromagnetic spectrum.

using a device's antenna beamwidth to approximate the antenna patterns and possible interference amongdevices. Further details about the Line of Sight and Cone Intersection algorithms may be found in [8].

B. Stage 4 - Friis Calculation

In Stage 4, the power received by each user due to every other user is calculated. These manifolds are compared pairwise using a Friis calculation, as shown below,

$$P_r = P_t G_t G_r \frac{\lambda}{4\pi R} \quad . \tag{1}$$

If a given transmission power of one device is greater than another device's tolerance, it is determined thatthere is a potential for interference between devices and the broker proceeds to the next stage of the culling process.

III. Stage 5 - Out of Band and Harmonic Interference Compensation

In addition to in-band interference from an intentionally transmitted signal, it is also possible for out-of-band interference. A simple algorithm was created to account for possible out-of-band interference as shown in Fig 3.

For out-of-band interference if the desired transmission band is within three bandwidths of the other indicated receive band on either side, then out-of-band interference is determined to be possible:

$$f \leq \pm 3 f_0. \tag{2}$$

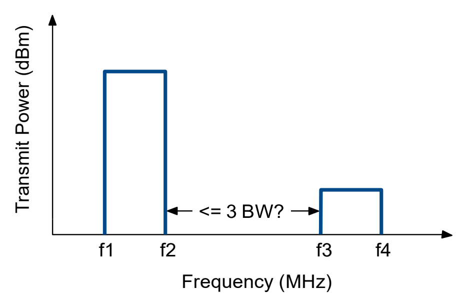

Fig. 3: Out of band interference approximation

Harmonic interference is determined by calculating if the desired receive band overlaps twice the frequencies of the requested transmit signal where f_{t1} and f_{t2} are the upper and lower frequencies of the transmit band, then there could be interference within a range of frequencies,

$$2f_{t1} \leq f \leq 2f_{t2} \tag{3}$$

IV. Spatial-Spectral Map Determination

The Friis transmission equation in 1 can be used to generate a spectral mask considering all devices with known position and interference powers [9]–[12]. Therefore using (1), a spectral mask, S_t can be generated, given the spherical coordinate system R and φ, the gainsof the transmitter and the receiver, G_t and G_r, and the receive power, P_r:

$$S_t(f) = \min_{0 \leq R \leq \infty, 0 \leq \varphi \leq 2\pi} P_r(f, R, \varphi) \frac{(4\pi R)^2}{G_t G_r \lambda^2} \quad . \tag{4}$$

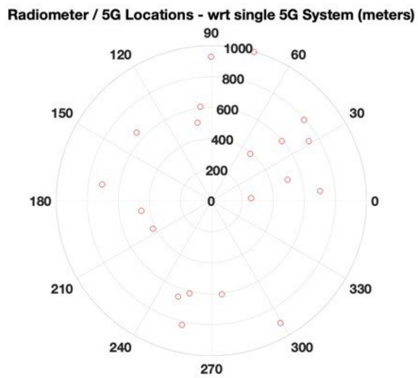

Fig. 4: Simulated spatial transmission scenario for several radiometer and 5G device locations with respect to a single 5G system.

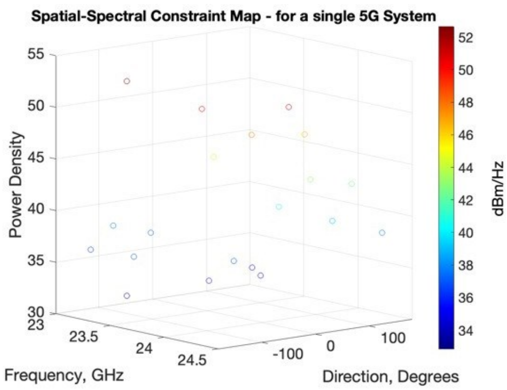

Fig. 5: An example spatial-spectral constraint map for 100 devices that are a mix of radiometers and 5G systems

All of the device requests to the broker contain aknown position and interference power in Watts/Hz. Fig. 4 shows a simulated spatial transmission scenario for several radiometer and 5G devices with respect to a single 5G system submitted to the broker. Fig 5 shows an example spatial-spectral constraint map for 100 devices that are a mix of radiometers and 5G systems determined using the spatial, spectral and calculated Friis tolerances. This spatial-spectral constraint map is then passed onto the 5G system or other transmitter and can be used to create a waveform that conforms to these constraints[13]–[17].

V. Conclusions

Increasing demands on spectrum means more complex and adaptive solutions are required to better utilize the finite amount of usable spectrum. Dynamically adaptive brokers can take into account both active and passive devices, allowing for the protection of critical systems, such as radiometers, and making it less likely that other transmitters may interfere. By taking into account both in-band and out-of-band transmissions interference between devices could be mitigated. Further, by de- termining a spatial-spectral constraint map for active transmitters, spectrum could be better utilized by trans- mitting only in directions and at frequencies where no interference was found when creating the spatial-spectralmask.

Acknowledgments

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