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Dynamic Spectral Mask Construction for Radar Transmission Based on Communication Receiver Locations

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***Abstract*— Dynamic spectrum allocation is becoming a means of allocating spectrum based on users and available frequencies in surrounding geographic regions. Presently, spectral masks are applied to radar transmission based on specifications from governmental regulatory agencies. This paper describes a concept for dynamic spectral mask determination based on the location and acceptable interference power levels at frequencies used by nearby communication receivers. This concept will be applied going forward to allow information from wireless networks about surrounding users to be applied in dynamically constraining radar transmitter spectra.**

***Keywords*— cognitive radar, spectral mask, power amplifiers, interchannel interference**

I. INTRODUCTION

Sharing spectrum between radar and communications applications is becoming more difficult due to the prevalence of wireless broadband transmission and the consistent increase in users of the frequency spectrum. Clever non-disruptive approaches will need to be innovative to provide enough spectrum for these ever-growing applications, many of which are governmental and safety-related.

A new and growing approach for sharing spectrum is dynamic spectrum allocation, where frequency bands may be borrowed temporarily from primary users if they are not using their systems. An example of this is in the 5 GHz band, which is presently shared between radar and WiFi communications. To use this spectrum where radar is the primary user, the WiFi system must check for radar transmission before using the frequency band. If a radar is detected in the band at any time during use, the WiFi system must immediately vacate the spectrum.

Radar transmissions are important for many applications, such as weather, air traffic control, homeland security, and defense. Because radar bands are now being increasingly shared with communications, particularly wireless 4G, radar designers and operators are concerned about the availability of spectrum for their important functions. Typically, radar transmission is bounded by a spectral mask, assigned by governmental agencies such as the National Telecommunications and Information Administration (NTIA) or Federal Communications Commission (FCC) in the United States. In the new proposed approach, a spectral mask will be determined based on (1) the location of surrounding communication users, (2) the frequencies of operation of the communication users, and (3) the acceptable interference power levels at each communication receiver at its operating frequency. This approach will allow radar transmission to be optimized and to successfully perform its functions while ensuring it does not interfere with communication users. Being able to use this approach will enable a new paradigm for spectrum sharing that will open spectrum to numerous additional users.

The scenario considered in our work pertains to adaptive radar transmitters. Cognitive radar is introduced by Haykin as a radar that can sense and respond to its environment [1], and Guerci discusses the concept of a knowledge-aided cognitive radar [2]. Haykin discusses the control of radar transmitter power level so that the acceptable interference temperature of receivers is not exceeded [3], and discusses adapting the transmitted waveform based on a multi-objective trade-off [4]. However, much of the previous work describing the mechanics of determining a transmit waveform based on other users has been in the area of communications transmission, rather than radar. Our work focuses on crafting radar transmission that is sensitive to nearby communication handsets. Mahmoud discusses spectrum shaping based on the presence of licensed users and a flexible spectral mask, noting that orthogonal frequency division multiplexing (OFDM) waveforms can provide spectral flexibility by either enabling or disabling subcarrier sets [5]. Poston discusses how OFDM waveforms can be woven among existing licensed television channels [6], and Cabric discusses placing a mask on the transmit power of an OFDM signal to protect adjacent-band users [7]. Srinivasa discusses combining cognitive radio transmissions with licensed user transmissions by placing a spectral mask on secondary user signals so that interference from the secondary transmissions is below the acceptable noise floor for primary signals [8]. The dynamic regulation of spectrum using market-based approaches is discussed by Delaere [9] and Xie [10].

The present paper describes the setup of how radar transmission spectral masks can be adapted based upon wireless handset users in the surrounding geographic region. This approach will allow circuit and waveform optimization algorithms developed by Fellows [11] and Eustice [12] to be applied based on surrounding spectrum users rather than on a traditional regulatory mask.

II. Spectrum Sharing Approach Overview

Consider a radar transmitter located near multiple communication receivers. It is assumed that the radar transmitter is located at coordinates (0,0), and communication receiver handsets are located at positions that are known. Further, the maximum acceptable power density that can be tolerated by the receivers at their operating frequencies are assumed to be known to the transmitter. This information might be known either through a wireless network in which the coordinates and acceptable interference levels are communicated to the radar, or through radar detection itself and estimated values of harmful interference based on whatever knowledge of the receivers is available. We have constructed a simulation setup in which receiver locations and acceptable power density can be randomly generated using MATLAB.

The Friis transmission equation allows calculation of the power at a receiver (P_r) based on the transmitted power (P_t), the distance from the transmitter to the receiver (R), and the antenna gains of both the transmitter and receiver antennas (G_t, G_r) [13]:

$$P_r = \frac{G_t G_r \lambda^2}{(4\pi R)^2} P_t \quad (1)$$

To simplify the problem, isotropic radiation is assumed for both the transmitter and receiver antennas. In a real scenario, this is far from accurate. However, it can be seen that these scenarios can be easily placed into consideration using equation (1). For isotropic radiation, $G_t = G_r = 1$ in (1) to allow simple solution, based only upon the distance between the transmitter and receiver, the frequency of the receiver, and the acceptable interference power at the receiver. Thus we can write (1) as

$$P_r(f, R) = \left(\frac{c}{4\pi R f}\right)^2 P_t(f) \quad (2)$$

where we have set

$$f = \frac{c}{\lambda}$$

assuming free-space transmission. Assume there are N handsets, the nth of which has parameters (R_n, f_n, p_n) where

- R_n is the distance from the transmitter to the nth communication handset,
- f_n is the frequency at which the handset operates, and
- p_n is the maximum acceptable power per bandwidth to the nth handset.

We will assume

$$f_1 \le f_2 \le f_3 \le \cdots$$

Then, from (2), if $P_r(f_n, R_n)$ is the power received by the nth handset, then we require

$$P_r(f_n, R_n) = \left(\frac{c}{4\pi R_n f_n}\right)^2 P_t(f_n) \le p_n$$

or

$$P_t(f_n) \le \left(\frac{4\pi R_n f_n}{c}\right)^2 p_n \quad (3)$$

Figure 1 shows the construction of a mask for a simple example using 4 handsets. In the case shown, the mask is placed a certain specified level below the maximum acceptable power.

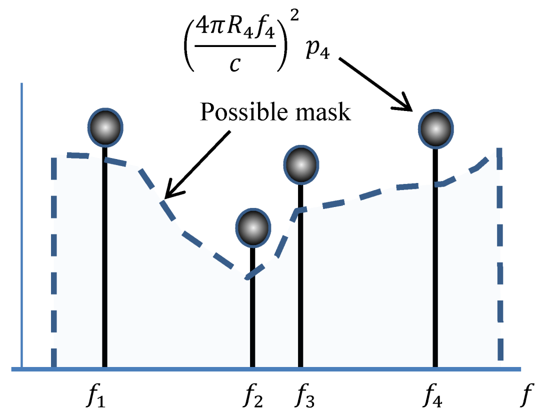

Fig. 1. Spectral mask construction based on the transmitted power related to maximum acceptable power at the handsets and handset positions and operating frequencies.

To solve in dB for the transmitted power, the logarithm of (3) is computed:

$$10\log_{10}[P_t(f_n)] \le 20\log_{10}\left(\frac{4\pi}{c}\right) + 10\log_{10} p_n + 20\log_{10} R_n + 20\log_{10} f_n$$

So in terms of dB

$$P_t^{dB}(f_n) \le C + p_n^{dB} + 20\log_{10} R_n + 20 f_n^{Dec}$$

where $f_n^{Dec} = \log_{10} f$ measures frequency in decades and $C = 20\log_{10}\left(\frac{4\pi}{c}\right)$ is a constant.

III. Special Cases

1. **Constant Range and Acceptable Handset Power:** If

$$R_n p_n = \text{constant},$$

then the allowable transmitted power increases 20 dB per decade. This means that the allowable transmitted power to avoid interference with a given handset with fixed position and maximum acceptable interference power density (dBm/Hz) increases 20 dB per decade. As a result, when radar transmit power is held constant, interference is less likely at higher frequencies. However, for the same reason, the radar transmitter must transmit with a power that is higher by 20 dB per decade to illuminate a target at fixed distance, and with a power that is higher by 40 dB per decade to achieve the same power in the echo at the radar receiver. Thus, this tends to be a deceiving scenario: for radar operation it may actually be better to operate at lower frequencies in many cases.

2. **Worst Case**: Rather than fitting to each individual communication handset's requirements, the mask can be

piecewise fit to the worst case over given intervals if desired. This provides a smoother mask which is, in most cases, more restrictive on the radar transmission. Assume the parameters can be constrained by intervals

$$f_- \leq f_n \leq f_+.$$
$$p_- \leq p_n \leq p_+$$
$$R_- \leq R_n \leq R_+$$

Then at that distance, (3) becomes

$$P_t(f_n) \leq \left(\frac{4\pi f_n R_n}{c}\right)^2 p_n \leq \left(\frac{4\pi f_+ R_+}{c}\right)^2 p_+,$$

where, for each parameter, we have chosen the upper limit of the allowable interval. This corresponds to a rectangular mask with

$$A = \left(\frac{4\pi f_+ R_+}{c}\right)^2 p_+.$$

Note the closer the handset is to the transmitter, the lower the mask amplitude. This rectangular mask is shown in Fig. 2.

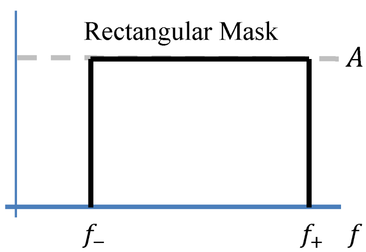

Fig. 2. Rectangular "worst case" mask over a frequency interval $f_- \leq f_n \leq f_+$.

3. **Cell Specific**: Equation (3) is satisfied when

$$P_t(f_n) \leq \left(\frac{4\pi}{c}\right)^2 \min_n R_n^2 f_n^2 p_n$$

which gives us the rectangular mask with

$$A = \left(\frac{4\pi}{c}\right)^2 \min_n R_n^2 f_n^2 p_n$$

A single worst case handset determines the mask amplitude.

4. **Piecewise Constant Sub Band Approach**: Divide the band over $f_- \leq f \leq f_+$ into M sub bands with interval ΔW. The first band would be from $f_- \leq f \leq f_- + \Delta W$. The mth band is over the interval

$$f_- + (m-1)\Delta W \leq f \leq f_- + m\Delta W$$

Over the mth band, we require

$$P_t(f) \leq \left(\frac{4\pi}{c}\right)^2 \min_n R_n^2 f_n^2 p_n,$$

where f and f_n are in the mth frequency band. Figure 3 shows the spectral mask construction for the piecewise constant sub-band approach.

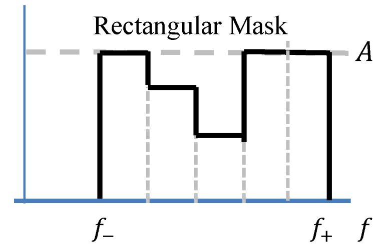

Fig. 3. Spectral mask for the piecewise constant sub-band approach

5. **Piecewise Constant Approach:** First, from (3), evaluate

$$P_t(f_n) = \left(\frac{4\pi R_n f_n}{c}\right)^2 p_n \quad (4)$$

for all n. Run a fixed length min sliding window over the series to get the mask. Figure 4 shows an example of this approach.

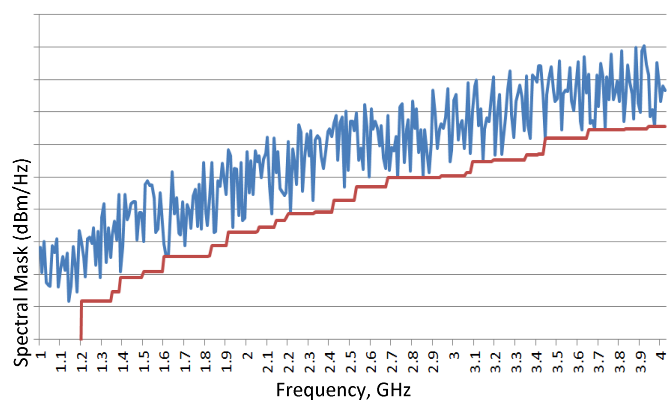

Fig. 4. Plot of piecewise constant approach to constructing a spectral mask based on a sliding window scale. The blue line represents the connected maximum acceptable transmit power density and the red line represents the sliding-window spectral mask.

III. Simulation Results

A simulation setup has been created in MATLAB to allow the development of this tool, which we plan to develop with increasing complexity. Use of this developing tool is briefly demonstrated using two simple scenarios. The frequency band from 3400 to 3700 MHz is used for illustration purposes, as this is a band that is presently used (at least in part) for spectrum sharing between radar and communications. In fact, much of the S-band radar allocation has been re-allocated for radar and communications sharing. The handset acceptable power density (dBm/Hz), frequency, and location can either be either randomly generated by the program or input on a spreadsheet to the program.

A. Simulation A

Figure 5 shows a simple scenario in which the radar transmitter, notated in red, is located at the coordinates (0,0) and handset receivers are located at the positions marked by 'X' on the diagram. 10 handsets are used, all with frequencies between 3400 and 3700 MHz (this frequency range represents an actual frequency range where radar and communications spectrum sharing is in use). The handset settings are generated using the following inputs to the random generator used in MATLAB:

- Maximum receiver acceptable power density range: -75 to -65 dBm/Hz
- Radar transmitter power density: 20 dBm/Hz
- Frequency range: 3400 to 3700 MHz
- X location: -50 to 50 meters
- Y location: -50 to 50 meters
- Number of devices: 10

Based on the frequencies and locations of the handset receivers, the receiver acceptable power density, and the radar transmitter power density needed for the radar application, the spectral mask can be dynamically constructed. Figure 6 shows the spectral mask for the scenario in Fig. 5. The algorithm chooses the main transmission band as 3.506 GHz to 3.573 GHz (bandwidth of 66.725 MHz), because this is the largest gap between communication receiver handset frequencies. The main transmission band part of the mask is indicated in red in Fig. 6. The remaining part of the mask, constructed based on handset data, is shown in blue.

The spectral mask is based on the power density of both the in-band transmission of the radar and the maximum acceptable power density transmitted at the frequencies of the handsets (traced to the transmitter using equation (2)).

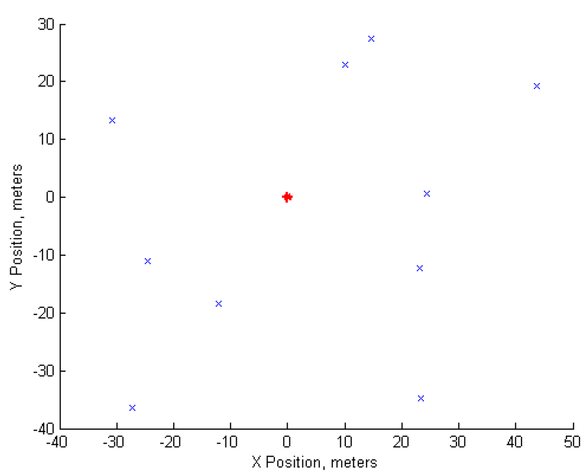

Fig. 5. Simulation A scenario with radar transmitter and communication receiver locations. The radar is notated in red and the handsets are in blue.

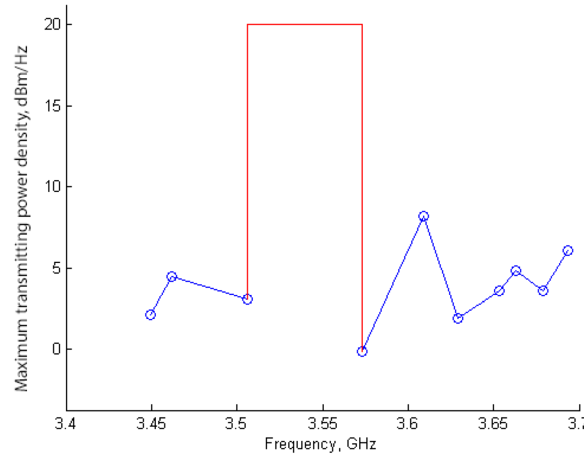

Fig. 6. Simulation A spectral mask for radar transmission based on acceptable power density levels at each communication receiver. The spectral mask has a bandwidth of 66.725 MHz, with a low frequency of 3.506 GHz and a high frequency of 3.573 GHz.

B. Simulation B

A second simulation was performed using the following settings. A notable change in this simulation is the much larger number of devices: 1500 communication receiver handsets are used, all with operating frequencies between 3400 and 3700 MHz.

- Maximum receiver acceptable power density range: -85 to -65 dBm/Hz
- Radar transmitter power density: 20 dBm/Hz
- Frequency range: 3400 to 3700 MHz
- X location: -50 to 50 meters
- Y location: -50 to 50 meters
- Number of devices: 1500

The locations of the communication handsets are shown in Fig. 7, assuming that the radar transmitter, again notated in red, is located at the coordinates (0,0). This is a very busy environment. In Fig. 8, the dynamic spectral mask is plotted by connecting the maximum transmit power density at the handset frequencies to the in-band transmission power. Again, the algorithm selects the widest frequency range available in the pre-specified range to perform the transmission. Because of the significantly higher number of devices, it can be seen that the bandwidth for transmission is 1.312 MHz, significantly smaller than in Simulation A. This will force the radar transmitter to adjust to fit a tighter spectral mask. The difference between Simulations A and B represents a scenario in which a radar transmitter must adapt from a less crowded to more crowded wireless environment.

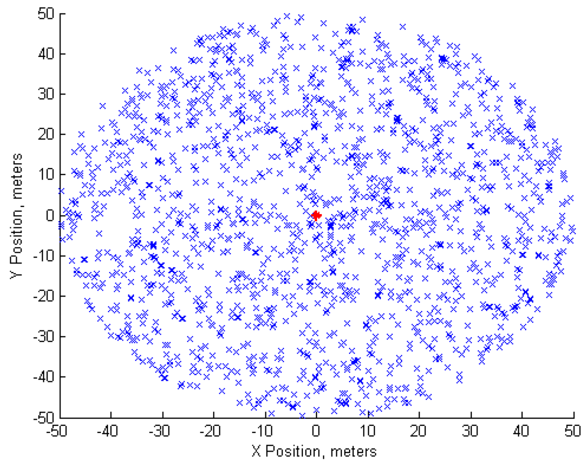

Fig. 7. Simulation B scenario with radar transmitter (red) and communication receiver locations (blue).

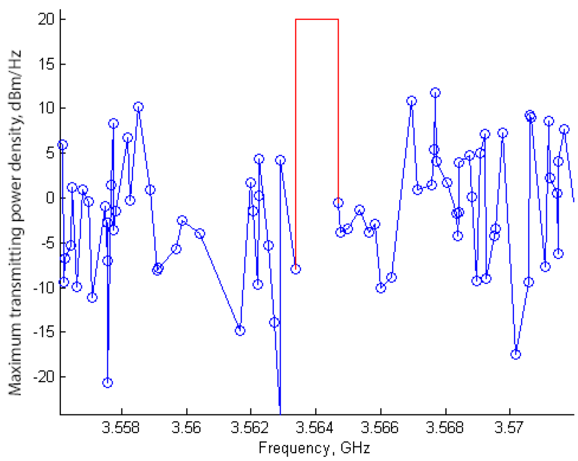

Fig. 8. Simulation B spectral mask, zoomed in for clarity, for radar transmission based on acceptable power density levels at each communication receiver. The spectral mask has a bandwidth of 1.312 MHz, with a low frequency of 3.543 GHz and a high frequency of 3.565 GHz.

IV. Conclusions

An initial simulation has been presented for the creation of a dynamic spectral mask for radar transmission based on the locations and maximum acceptable power density levels of surrounding communication receiver handsets, which would ensure that a wireless communication receiver does not become victimized by the radar transmission. This work represents a first step toward a more complex platform in which the spectral mask for radar transmission is based on its surroundings and on system specifications. This platform can be expanded upon by considering directivity of the radar transmitter and communication receiver handsets, and other complicating factors such as atmospheric attenuation and radar transmitter rotation.

Next steps to expanding this work include using the dynamic spectral mask to control load impedance [11] and waveform optimizations [12]. Putting this framework in place explores the upper-level scenario control of the algorithms that will provide for reconfigurable radar transmitters to optimize their circuitry and waveform to meet spectral output requirements while achieving desired range/Doppler resolution requirements (based on the ambiguity function) and power-added efficiency.

Acknowledgment

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