Marcus Spectrum Solutions

Thoughts on Radar/Communications Spectrum Sharing*

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[The author would like to thank the organizers of ISART 2011 for their kind invitation to speak. But due to a conflicting family event he is unable to attend. However, recognizing the important of this year's theme, "Developing Forward-Thinking Rules and Processes to Fully Exploit Spectrum Resources --Case Study 1: Radar Bands", he is providing this input to further discussion on this key topic.]

Wireless communications is a key infrastructure in today's economies and societies. Spectrum is a key building for such wireless systems and is a key component for governmental[1] systems that are essential to security. Classically these two uses of spectrum have been mostly viewed as a "zero sum game", that is spectrum could be either used for nongovernmental communication uses or for governmental applications. There is sharing, but it generally is on a regional basis or a frequency by frequency basis, so the two classes of users are not on the same frequency at the same location.

But the need for spectrum is too great now to let this traditional viewpoint continue unchallenged. Economic security is also now recognized as a key aspect of national security.[2] Finally, the national security budget is now in the 3-5% of GDP range and any increases in national security spending will have to be tied to GDP growth under the current and foreseeable budgeting paradigms. Thus the national security community should consider with "what's good for the GDP, is good for national security".

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* The thoughts presented here *are* the opinions of Marcus Spectrum Solutions LLC but are not necessarily the view of any of its clients.

[1] In this paper, I am using "government" in its generic usage, not the US spectrum management usage where it refers to federal government spectrum use.
[2] "To achieve the world we seek, the United States must apply our strategic approach in pursuit of four enduring national interests:

- Security: The security of the United States, its citizens, and U.S. allies and partners.
- <u>Prosperity: A strong, innovative, and growing U.S. economy in an open international economic system that promotes opportunity and prosperity.</u>
- Values: Respect for universal values at home and around the world.
- International Order: An international order advanced by U.S. leadership that promotes peace, security, and opportunity through stronger cooperation to meet global challenges." (emphasis added)

White House, National Security Strategy, May 2010, p. 17 (http://www.whitehouse.gov/sites/default/files/rss_viewer/national_security_strategy.pdf)

The UK government has looked at the general spectrum problem and its counterpart of the US Executive Branch has declared

> Spectrum is a valuable resource that enables growth and innovation by the private sector. Spectrum is also essential to the running of public services including defence, emergency services and transport. However, as part of the Government's drive to manage more effectively the nation's assets, we are committed to releasing surplus public sector spectrum to more productive private sector use.[3]

In the US, radar has been classically a major use of spectrum by federal government agencies. While there has been some very limited sharing on a geographical basis, the general view has been that such spectrum could not be shared with communications systems since the nature of the uses were so different. But new advances in communications technology and in the evolving nature of wireless communications mean that we should reexamine sharing options.

I. U-NII DFS Transparency Urgently Needed

On November 12, 2003 FCC approved the Report and Order in Docket 03-122[4] authorizing unlicensed device/radar sharing in the 5.25-5.35 GHz and 5.470-5.725 GHz bands. An earlier January 31, 2003 NTIA announcement stated

> The NTIA, FCC, NASA and Department of Defense (DoD), working closely with industry in detailed technical meetings, have agreed to modify the required Dynamic Frequency Selection (a listen-before-transmit mechanism) detection threshold characteristics contained in the U.S. proposal for WRC-03 Agenda Item 1.5.[5]

Since the adoption of these rules it has become clear that there have been recurring interference incidences, particularly involving the FAA's Terminal Doppler Weather Radar (TDWR) system. There appear to be three possible causes of this interference:

1. U-NII devices using the radar bands lack the dynamic frequency selection (DFS) capability required by 47 C.F.R. 15.407 either because it was not included in the design or because it was disabled through a software change after the design was approved.
2. U-NII devices with DFS capability but due to testing ambiguity they were not capable of the performance expected by those who drafted the agreement announced by NTIA on 1/31/03
3. U-NII devices met the capabilities expected in the agreement, but these DFS features were not adequate to prevent interference in specific circumstances

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[3] "Enabling UK growth – Releasing public spectrum:Making 500 MHz of spectrum available by 2020", March 2011 http://www.culture.gov.uk/images/publications/Spectrum_Release.pdf
[4] http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-03-287A1.pdf
[5] http://www.ntia.doc.gov/ntiahome/press/2003/5ghzagreement.htm

It is clear from both a November 2010 NTIA/ITS report[6] and from FCC enforcement cases that are on the public record that some cases[7] fall in the first category. It appears that some also fall in the third category where the standard adopted by FCC after consensus with industry and NTIA was not adequate to prevent interference. This is the clear conclusion of the July 27, 2010 memo from FCC's Office of Engineering and Technology and Enforcement Bureau[8] to "Enforcement Manufacturers and Operators of Unlicensed 5 GHz Outdoor Network Equipment". The memo states,

> "We have found that the interference at each location has generally been caused by a few fixed wireless transmitters used by wireless internet service providers (WISPs) and operating outdoors in the vicinity of airports at high elevations that are line-of-sight to the TDWR installations (5 GHz outdoor network equipment). In most instances, the interference is caused by operations in the same frequency band as TDWRs, but there are some instances where the interference is caused by adjacent band emissions."

The existence of cases in the third category is also seen in an NTIA presentation at last year's ISART.[9] However in both the case of the first category and the third category cases, these is no explanation on the public record as to the root causes of these problems. In order to develop future cognitive radio systems that share with radars on a noninterference basis, we need to learn from problems such as this one. As George Santaya wrote, "Those who cannot learn from history are doomed to repeat it."

The cognitive radio research community learned about the TDWR interference through cryptic FCC and NTIA statements, but there has been no technical information released to date on the specifics problems that arise from properly working DFS systems in high antennas near TDWR systems. The power budget modeling that was used in making the January 2003 agreement appears to have been wrong in the case of TDWR, yet there is no quantitative information on what we have learned on how to model these situations better. While some of the military radars involved in the 2003 analysis are classified, the TDWR appears to be an unclassified system so it is hard to believe that there is a valid national security justification for with holding information on the nature of the interference and why operational experience differs from the models used in 2003. While there is not a need to identify personal or organizational responsibility here, there is a need to understand the technical issues involved.

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[6] NTIA/ITS, Case Study: Investigation of Interference into 5 GHz Weather Radars from Unlicensed National Information Infrastructure Devices, Part I; NTIA Report TR-11-473, November 2010 (http://www.its.bldrdoc.gov/pub/ntia-rpt/11-473/)

[7] http://www.fcc.gov/Daily_Releases/Daily_Business/2011/db0217/DA-11-306A1.pdf

[8] http://www.wispa.org/wp-content/uploads/2010/05/FCC-Memorandum-on-UNII-Device-Operartion-July-27-2010-1.pdf (sic)

[9] Frank Sanders (NTIA), "5 GHz DFS Technology Devvelopment and Deployment: Challenges Met and lessons Learned", Presentation at ISART 2010(July 2010) http://www.its.bldrdoc.gov/isart/art10/slides_and_videos10/DFS%20development%20and%20lessons%20learned%20FHS.pdf

There have also been hints that some of the interference is due to first category – DFS systems that were disabled after they were tested and approved. In particular the AT&T/San Juan case[10] seems to be in this category. The original software defined radio (SDR) rules adopted in Docket 00-47 in September 2001 were relaxed in Docket 03-108 at the request of industry. The original rule[11] required protection against tampering, such as authentication codes, for *all* equipment where the software can change the unit's parameters. The current rules only require such protection if the unit is *marketed* as being changeable by the end user. FCC and NTIA should be more forthcoming as to whether some of the TDWR interference encountered was caused by software disabling of DFS function in units that are not subject to security requirements and testing in the former 2.932(e) as a result on the Docket 03-108 changes.

The author urges FCC and NTIA to use the occasion of ISART 2011 and the ensuing dialogue on communications/radar sharing to make a full technical disclosure on the nature and causes of the TDWR interference.

II. Design of *New* Radar and Communications Systems with Sharing as an Objective

The basic problem that the 5 GHz DFS system has is that the various radar systems it has to share with on a noninterference basis were not designed with sharing in mind. (The fact that the sponsors of these radar systems are basically the "judge and jury" for determining the risk of interference in any sharing scheme under today's spectrum policy arrangements also complicates things.) I explored this general issue in my 2007[12] and 2010[13] DySPAN papers.

The basic point on cooperative sharing vis-à-vis passive sensing is shown below:

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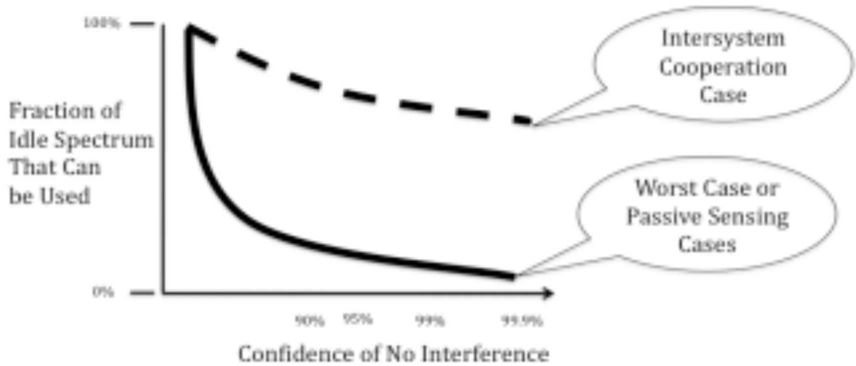
[10] http://www.marcus-spectrum.com/Blog/files/d7110e2482463dd2de998df926ceea1f-191.html

[11] "2.932(e) Manufacturers must take steps to ensure that only software that has been approved with a software defined radio can be loaded into such a radio. The software must not allow the user to operate the transmitter with frequencies, output power, modulation types or other parameters outside of those that were approved. Manufacturers may use authentication codes or any other means to meet these requirements, and must describe the methods in their application for equipment authorization."(Rules adopted in Docket 00-47)

[12] http://www.marcus-spectrum.com/resources/Marcus-DySPAN07a.pdf

[13] http://www.marcus-spectrum.com/documents/DySPAN10.pdf



In a cognitive radio or dynamic spectrum access system that depends solely on passive sensing of primary, e.g. radar, signal the only way to get a high confidence of noninterference is to use a small fraction of the idle spectrum. The probability of detection must be set so high that the probability of false alarm is very high – a false alarm meaning here that idle spectrum can not be used.

Designs with intersystem cooperation can potentially achieve much higher spectrum use with the same interference risk. This is because cooperative systems can effectively emulate nonrealizable systems, that it, systems that can predict the future based on other than past observations. The best DFS system can only make statements on past observations – if the primary system is about to turn on or change parameters it can not know that until after it happens. Allowing for such events requires more conservative sharing parameters as are seen in the 5 GHz DFS case.

But cooperative systems can share information about present and future transmissions and hence have more effective spectrum sharing while maintaining a low interference risk.

A. Changes in Wireless Spectrum Use Today

Before we get into cooperative radar/communications system design it is necessary to make an observation on trends in today's wireless spectrum use. Traditionally the wireless industry sought paired spectrum for full duplex operations. While the national Broadband Plan[14] does not state so explicitly, the 500 MHz of additional spectrum sought in Recommendation 5.8 is presumably full duplex spectrum. It is also unstated but presumed that this spectrum is full time availability spectrum - that is that it is available 24/7 **and** 1000 ms/1s.

When wireless use was predominantly 2 way voice these presumptions made sense. However, this is not the growth area in today's spectrum use. Total voice minutes may be actually declining. Today's growth in wireless communications is in packetized

[14] http://www.broadband.gov/download-plan/

information and is generally asymmetric in its uplink/downlink ratio. Wireless spectrum users do not actually want spectrum, they want communications capacity![15]

Having asked for symmetric spectrum for 3G applications the wireless industry may be regretting that it got what it asked for. While carriers are secretive about the specific asymmetry of their present traffic load, it is clear that downlink traffic dominates and will continue to dominate. Furthermore, most of this packetized asymmetric traffic can be handled with more time delay flexibility than voice or 2 way video. While some user may want to pay a premium for very low latency communications, there may well be a market for latencies in the 0.5s – 2s range. Note also that the services offered by Sirius/XM have a latency resulting from time diversity used to control momentary path outages and few users have ever noticed it. Finally today's packet switching technology allows the design of systems that reroute packets on a real time basis as communications channels become available or unavailable.

B. Radar/Communications *Joint* Design

A key aspect of the development of the B-2 stealth bomber was that for the first time aeronautical engineers and electromagnetic engineers worked on an integrated team to design an innovative aircraft that could both fly well to perform its mission and have a negligible radar cross section. Similarly, there are tremendous benefits possible for joint design of communications and radar systems to share the same spectrum. The *ex post facto* approach used for 5 GHz DFS is doomed to have limited utilization of available spectrum.

Most noncombat radars rotate, most with mechanical rotation, a few with electronic rotation. Thus at a given moment the RF power is focused in one azimuth and that azimuth is changing with time. Similarly the radar receiver is focusing on one azimuth also. The antenna pattern governs how well focused the transmitter and receiver are and finite size antennas must inevitably have sidelobes and backlobes. But antenna design techniques exist to reduce such sidelobes and backlobes although designers of radars not subject to jamming and with access to plenty of spectrum have little incentive to use them. The antenna pattern for many federal radar systems are regulated by Chapter 5 of the *NTIA Manual of Regulations and Procedures for Federal Radio Frequency Management* ("Redbook").[16] Radar Spectrum Engineering Criteria (RSEC) C and D apply to many federal radar systems.[17] The main requirement for rotating antennas is a

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[15] Note that radar users, by contrast, often *can* convert their requirements into bandwidth since radar performance in many cases is directly related to bandwidth since bandwidth is inversely proportional to ambiguity function width in the time domain.

[16] http://www.ntia.doc.gov/osmhome/redbook/ed200801rev201009/5_9_10.pdf Note that unlike the FCC Rules, these requirements are not legally binding on federal users authorized by NTIA in that NTIA can give alternative limits in specific authorizations and the details need not be made public.

[17] Redbook 5.5.3.5 and 5.5.4.5 There is not stated general criteria for radars with rated peak power less than 100 kW. The present requirements are

median gain of -10 dBi in the "principal horizontal plane". While this amount of sidelobe suppression might have been appropriate in the past when spectrum was less in demand, better suppression is likely available today and could be facilitated by cost sharing between radar users and spectrum sharing parties. Note that nonrotating radars are already subject to 26 dB suppression relative to the main beam.

While the specific performance details, including sidelobe levels, of operational military antennas are appropriately classified, a key question is whether the current "Redbook" limits are the best achievable with today's technology, or a historical goal. We note that level of sidelobe suppression is consistent with a 1958 open source article.[18] Any antenna of finite aperture *must* have sidelobes, although their levels are a function of antenna size, aperture illumination taper, aperture blockage, reflector surface errors and feed misalignment, and reflectivity of feed support.[19] For phased array antennas some of these factors disappear but new factors appear due to the discreteness of the current and phase shifts over the aperture. Radio telescope antennas share many characteristics of radar antennas and low sidelobe levels are useful for both. However, while radar operators can use regulatory tools to limit cochannel spectrum use, radio astronomers can not do so for observations of molecular resonances that are not in primary radio astronomy (RA) allocations. Thus the RA community has been aggressively pursuing novel antenna designs the suppress sidelobes.[20] One recent example is the Robert C. Byrd Green Bank Telescope which achieves 12 dB better suppression than a *similarly sized* conventional

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> Since electromagnetic compatibility considerations involved phenomena which may occur at any angle, the allowable antenna patterns for many radars may be usefully described by "median gain" relative to an isotropic antenna. Antennas operated by their rotation through 360 degrees of the horizontal plane shall have a "median gain" of –10 dB or less, as measured on an antenna test range, in the principal horizontal plane. For other antennas, suppression of lobes other than the main antenna beam shall be provided to the following levels, referred to the main beam:
>
> first three sidelobes--17 dB;
>
> all other lobes--26 dB."

[18] McCoy, A.; Walsh, J.; Winter, C.; "A broadband, low sidelobe, radar antenna" *WESCON/58 Conference Record* Volume: *2* , Part: 1 (1958) , Page(s): 243 - 250

[19] Shahnaz Bibi ; Nadeem Faisal ; Xie ShuGuo ; "Analysis of Low Side Lobe Reflector Antenna", Multitopic Conference, 2006. IEEE INMIC '06, p. 383

[20] It is assumed that the military radar community has also been aggressive in this area, but since sidelobe performance affects jamming vulnerability there are valid national security reasons to be secretive about sidelobe levels of specific military radars. We note, for example, that the manufacturer of the AWACS radar system refers to its "Ultra-Low Sidelobe Array". (http://www.es.northropgrumman.com/solutions/awacs/assets/AWACS.pdf) No quantitative information on AWACS sidelobes is in the public domain, but a paper from the AWACS manufacturer states that "ultralow" means sidelobe levels "below -40 dB". (Hacker, P.; Schrank, H.; "Range distance requirements for measuring low and ultralow sidelobe antenna patterns"; *IEEE Transactions on Antennas and Propagation*, Volume: *30* Issue: 5 Page(s): 956 – 966, 1982) It is assumed that technology transfer of some of the features of this radar to other federal government radars is possible if key details were kept classified and the nonmilitary user compensated for the marginal cost of improved sidelobe performance through cost sharing with other spectrum users.

antenna.[21] Similar design techniques, as well as lessons learned from military antenna designs, could reduce the sidelobes of radar antennas to facilitate sharing.

Some of these reduction techniques involve increased antenna size which is practical within limits at a cost in many terrestrial radar systems but much less practical in airborne or naval systems. Other techniques increase the complexity and cost of antennas. If the communications and radar systems were designed jointly then cost sharing between the two classes of user could be considered and joint tradeoffs made. While such cost sharing is not possible under current legislation and present FCC and NTIA policies, it is not an inconceivable change either given the present demand for spectrum and the focus on economic growth for both societal reasons and national security reasons as outlines above.

If the communications users had cooperative real time information on the beam azimuth and rotation rate (or in the case of electronically steered beams the future azimuths in general) then the communications users could adjust their temporal and spatial use of the frequency to minimize impact on the radar system. For example, more power could be used when the radar azimuth is antipodal to the communications user and power could be reduced to zero or near zero when the radar azimuth overlaps the communications users. This makes no sense for full duplex voice systems[22], but as stated previously this is not the type of wireless use where there is significant growth is today and is unlikely to be in the future. Packetized communications systems can effectively use this type of intermittent availability spectrum.

Joint design radar and communications signals can also improve the D/U ratios needed for the interference free use of both systems both considering both signal design and antenna polarization. Such a change in D/U protection could increase the amount of communications that could be used on an interference free basis in the radars coverage area and within its bandwidth. When the two types of systems can never be made completely orthogonal in either signal space or electrical polarization, every few dB decrease in signal crosscorrelation and in cross polarization coupling translates into more effective spectrum use. Joint design would allow the tradeoffs and cost allocations to be made to maximize the public interest.

III. Conclusions

It is in the public interest to maximize spectrum use by developing radar and communications systems designed from the beginning to share spectrum. Joint design would allow the marginal cost increases for the radar systems to be paid by the communications users that directly benefit from more sharing. Under present spectrum

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[21] http://www.gb.nrao.edu/gbt/gbtdesign.shtml

[22] Although it should be noted that VOIP-based voice systems could reroute packets to different physical channels during a call. However, voice telephone has time latency requirements that are much tighter than the other categories of mobile communications that are now dominating mobile use.

regulation, such spectrum sharing and cost sharing may be impractical, but pending legislation recommended by the National Broadband Plan would facilitate such sharing.