Radar Sharing in the U.S. 3 GHz Band

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***Abstract*— While the 3 GHz region of spectrum is being adopted in many areas of the world as prime spectrum for broadband deployments including 5G, this portion of spectrum in the U.S. is heavily encumbered by military radars. However, U.S. regulators and the Department of Defense have found ways to share portions of this band already and are studying ways to expand sharing of other parts of the band in the future. This paper provides an overview of the 3 GHz spectrum environment in the U.S., and, based on initial experiences, presents promising areas of research involving machine learning that can expand the efficiency with which this spectrum is shared.**

Keywords—wireless, radar, machine learning, radio spectrum management, cognitive radar

I. Introduction

There is a tremendous amount of interest worldwide in using "midband" (roughly 3 – 24 GHz) spectrum for broadband services, including 4G and 5G mobile broadband services. A particular range of interest is the 3 GHz region, which has extensive allocations in various regions around the world for mobile broadband and is designated for 4G LTE and 5G-NR by 3GPP, which has defined LTE bands 42, 43, 48, 49, and 52, and 5G-NR bands n48, n77, and n78 that cover various portions of the 3 GHz band.

In many parts of the world, the 3 GHz range is relatively unencumbered, which is one characteristic that makes it desirable for new mobile broadband services. In the U.S., however, the band is heavily encumbered by shipborne, airborne, and ground-based military radar systems. Despite these encumbrances, the U.S. Federal Communications Commission (FCC, which regulates civilian use of the spectrum) has worked with the U.S. National Telecommunications and Information Administration (NTIA, which regulates federal government use of the spectrum, including military) and the U.S. Department of Defense (DoD) have worked with industry to find ways to share some portions of the 3 GHz range, while also relocating some operations and studying options to share additional portions of the band.

In this paper, we'll explore the ways that mobile broadband is being accommodated in the U.S. 3 GHz band despite the radar encumbrances, then we'll discuss topic areas in which machine learning might be used to improve the spectrum sharing arrangements, by, for example, improving the resilience of radar systems to interference caused by mobile broadband, and/or improving the ability of commercial spectrum sharing systems to detect and avoid radar operations. Such developments could improve the operations of both radar and broadband systems and may alleviate the need to relocate some military radar systems out of the band, which is a lengthy and expensive process.

In many research efforts, first an elegant solution is derived, and then potential areas of application are sought. The purpose of this paper is to reverse that typical process by identifying and presenting policy and technical constraints that impact actual current and near-future spectrum sharing situations, and suggesting research avenues that can address such real-world challenges.

II. Radar/Broadband Shared Spectrum in the U.S. 3 GHz Band

A. Citizens Broadband Radio Service (3550-3700 MHz)

The U.S. Citizens Broadband Radio Service (CBRS) [10] supports relatively low-power (50 W max EIRP per 10 MHz outdoor; 1 W max EIRP per 10 MHz indoor) systems that provide rural broadband, enterprise networks, specialized networks for sports and entertainment venues, and a range of other applications. CBRS operates in the 3550-3700 MHz band on a non-interference basis to incumbent military radars and a small number of incumbent fixed-satellite service receive-only earth stations. This band is shared primarily with military radars that operate aboard Navy ships in coastal areas. CBRS base stations (called CBSDs) are managed by centralized cloud-based systems called Spectrum Access Systems (SASs), and must obtain permission from a SAS before transmitting, and then continually (every few minutes) thereafter. CBSDs must avoid causing interference to the incumbent radars, a process that is managed by the SAS, which reconfigures CBSDs (e.g., lowering their power, changing them to another frequency, etc.) when and where incumbent radars are operating.

A SAS becomes aware of incumbent radar operations in a variety of ways. Currently, the principal method is using a coastal sensing network, called an Environmental Sensing Capability (ESC). A typical ESC network is comprised of sensors located approximately every 100 – 200 km along the

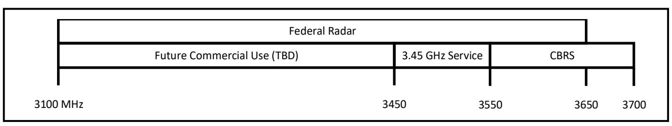

Fig. 1. The U.S. 3 GHz band spectrum environment.

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coastline, pointed out to sea, listening for incumbent radar activity. The sensors are tested and approved by the government based on their ability to detect specified types of waveforms that are used by current and near-future shipborne radars [9]. The siting of the sensors is also approved by the government to ensure adequate coverage of the areas in which the military's ships operate [11].

Currently, three commercial ESC networks are operating and successfully helping to protect military incumbents from harmful interference. There have been no reports of interference to protected incumbents since CBRS began commercial service in January of 2020. However, the use of ESC to protect incumbents has exposed shortcomings in the ESC framework that negatively impact CBRS users of the band.

First, ESC sensors must themselves be protected from interference so that they can detect the incumbent radar signals. Because the signals may be coming from a long distance out to sea, and therefore potentially quite weak, the interference protection criterion is fairly stringent: -109 dBm/MHz RMS aggregate co-channel interference from all CBSDs operating within up to 80 km of the ESC sensor site. The impact of this interference criterion is that ESC sensors create a "whisper zone" in their surroundings in which CBSD operations may be heavily constrained, such as limited EIRP, or even the inability to operate altogether [12]. Because ESC sensors are located in coastal areas, and most of the U.S. population lives in coastal areas, whisper zones can negatively impact several million potential CBRS users.

Second, the government-established detection criteria for determining when a radar is operating are quite stringent, requiring ESC sensors to declare a detection even after as few as 15 pulses over 15 milliseconds. When a sensitive receiver that implements these detection criteria is placed in a real environment, false detections can occur due to random pulse-like events caused by, for example, light switches, motors, electrical storms (both near and distant), adjacent-channel broadband signals, and even gaussian noise. The government-mandated detection requirements currently leave no room for evolving to more sophisticated detection algorithms that could reduce the number of false detections, but the government might entertain such changes in the future, if appropriate technical cases can be made.

Third, when DoD activity is occurring off-shore, the area in which CBSDs must be considered as potential contributors to aggregate interference to DoD radars is very large: in some parts of the U.S., these areas extend more than 350 km inland, encompassing huge populations of CBRS users. These distances are calculated by NTIA on the basis of an assumed CBRS deployment model, a pre-established propagation model, and the interference criteria of DoD shipborne radars. The large extent of these aggregate interference "neighborhoods" cause computational complexity for SASs and potentially disrupt CBRS operations for millions of users. The large sizes of these neighborhoods are due in part to what some believe are overly conservative propagation models. The model being used is the Irregular Terrain Model (ITM), which is based on the Longley-Rice model developed in the 1960s, using empirical data acquired in the 1950s. A reasonable question to ask is whether modern spectrum sharing rules should be based on propagation models that were created closer in time to the age of Marconi than today?

B. 3.45 GHz Service (3450-3550 MHz)

The FCC recently adopted rules for the new 3.45 GHz Service that will operate in the 3450-3550 MHz band [13]. The 3.45 GHz Service spectrum is immediately below the CBRS band. While CBRS base stations are limited to 50 W EIRP per 10 MHz, 3.45 GHz Service base stations are allowed much higher power, up to 32,800 W EIRP per 10 MHz. (Some measures to mitigate inter-band interference are being investigated by industry, such as TDD synchronization).

In the course of examining the expanded use of the 3 GHz band below CBRS for commercial systems, the NTIA and DoD released a report that examined their ability to clear and/or share various portions of the band [14]. For the 3450-3550 MHz band, the government concluded that many systems could be relocated to other frequencies, and/or their concepts of operation could be modified, to accommodate use of the band by commercial broadband systems. Such changes would take up to eleven years to implement. However, the government concluded that some systems would have to continue to operate in the band on an ongoing basis. The DoD has established geographic areas in which their systems would continue to operate and in which 3.45 GHz Service operators would need to coordinate their systems with DoD [15]. These areas are called Cooperative Planning Areas (CPAs). In some of those CPAs, the DoD will occasionally operate on a more intensive basis, which may periodically further impact 3.45 GHz Service operations. Such areas are called Periodic Use Areas (PUAs). Every PUA is coincident with a CPA, but not every CPA is a PUA.

C. The Rest of the 3 GHz Band (3100-3450 MHz)

The FCC and NTIA are examining the future of the rest of the 3 GHz band (3100-3450 MHz) that is currently occupied primarily by DoD [16]. Essentially, the DoD's use of the 3 GHz band for radar systems becomes more intensive towards the lower end of the band. This is due in significant part to DoD plans to accommodate the 3.45 GHz Service by relocating or constraining some systems that previously operated in the 3450-3550 MHz into frequencies below 3450 MHz.

FCC, NTIA, and DoD are currently studying the extent to which the 3100-3450 MHz band can be cleared and/or shared. Whatever option or options are adopted, it is a relatively safe bet that the extent to which commercial systems will have to share with military radar in this band is even more extensive than any other portion of the band. The only alternative is a very lengthy and very costly relocation of DoD radars out of this band entirely.

III. Improving Shared Spectrum Opportunities in the 3 GHz Band Using Machine Learning

Effective sharing between radar and communication systems requires an acute knowledge of interference between these systems. Studies by the NTIA have shown that out of band emissions from communications system base station transmitters operating between 2496–2690 MHz can cause unintended interference to weather radars operating from 2700–2900 MHz [1]. In addition, several studies have been conducted to assess specific radar interference to communication systems. Specifically, co-existence of TD-LTE and radars [2] and radar interference to LTE [3] that were both studied in the 3.5 GHz band, review the interference of radars to communication systems.

There is a further critical need for research on how both radar and communication systems interfere with each other in the 3 GHz band that can better inform cognitive radar and machine learning techniques. This research can further fuel cognitive radar technologies to better mitigate interference and assist sharing between communications and radar technology.

There are several important radars in the 3 GHz band, most notably the SPN-43 and the SPY-1. The SPN-43, an aircraft carrier-based air traffic control radar, is an older magnetron radar that operates from 3.5–3.7 GHz that will eventually be fully replaced by the SAAB AN/SPN-50(V)1 and moved to C-band. The SPY-1, which is on all AEGIS destroyers and cruisers (numbering nearly 100 U.S. ships), also operates in the 3 GHz band. It is a tube-based radar that when transmitting is generally very noisy in the sidebands, potentially leading to more interference to nearby communication systems.

These radars were designed before the advent of true cognitive radar [4][5] and are not solid state, though some modernization efforts have been made on the SPY-1. Further development needs to be completed for a solid state and more configurable radar to replace the SPY-1 as well as studies to investigate interference between this radar and nearby communication systems.

Newer systems in the band include the SPY-6 (previously known as the Air and Missile Defense Radar, AMDR), an active electronically scanned array deployed on the newest Ford-class aircraft carriers, and also scheduled to replace the SPY-1 radars on destroyers and cruisers [8].

The takeaway is that sharing between military radars and commercial broadband systems in the 3 GHz band is here to stay, and how that sharing is accomplished will have a major impact on both the ability to provide effective broadband services in the band, and on how much the military's operations are impacted and how much those impacts will cost in terms of both money and operational effectiveness. In consideration of those takeaways, some key research opportunities arise with regard to technical developments that can improve sharing effectiveness, reduce impacts to DoD, and reduce clearing and relocation costs.

A. Improvements in ESC Sensor Detection Algorithms

The requirements to declare a detection of incumbent military radar are prescribed by NTIA (in consultation with DoD) are quite basic. For example, the detection of the most common radar in the band must be declared upon reception of as few as 15 pulses at a rate of 900-1100 pulses per second (pps), with a pulse width of 0.5 – 2.5 microseconds [9]. In other words, declaration of detection can be the result of a range of pulse activity over as little as 15 milliseconds of time, with no follow-up or additional time to confirm detection. As a result, false detections can and do occur, caused by any number of radio frequency interference events in the vicinity of the sensor. Many potentially interfering signals incorporate a 1000 Hz cadence (1 ms timescale) as part of their physical layer standard (for example, an LTE subframe is 1 ms long), and therefore even adjacent channel interference from such systems can cause erroneous triggering of an ESC sensor. Natural interference, such as impulses from electrical storms and even gaussian noise, can trigger ESC sensors, given that such sensors are continually sampling the RF environment on sub-millisecond timescales (i.e., effectively more than 100 million samples per day) across 100 MHz of spectrum.

In theory, detecting a radar signature is simple. However, in real-world conditions in which potentially very weak radar signatures must be detected in the presence of interference and noise, the balance between reliably detecting a variety of radar signatures while reducing false positives is quite difficult.

B. Improvements in Interference Immunity of Radars

The required radar detection sensitivity of the ESC sensors (-89 dBm/MHz), and the interference criterion for those sensors (-109 dBm/MHz RMS aggregate co-channel interference), both set by NTIA in consultation with DoD [9], are ultimately determined by the interference criteria of the DoD radars that are being detected and protected. (Note that the interference criterion is equivalent to a 20 dB C/I objective). Those interference criteria are not published. However, it can be reasonably assumed that if the radar interference criteria were less stringent, then the radars could function closer to shore before land-based broadband systems would cause harmful interference, and therefore ESC sensors would not need to be as sensitive, since the radars that need protection would be closer.

Reducing the sensitivity of ESC sensors and increasing the strength of the signals they must detect would in turn result in fewer false positives, and therefore fewer unnecessary disruptions to CBRS operations as a result of erroneous detections of incumbent activity. Fewer disruptions would also occur because only those incumbent operations closer to shore would need to be protected; increased interference immunity of the radars would mean that the distance over which radars must be protected is less, and therefore those operations beyond that distance no longer would require disruption of CBRS service to avoid interference.

Further, reducing the sensitivity of ESC sensors would allow a relaxation of their interference criterion if the same 20 dB C/I criterion is maintained. In turn, a relaxation of the ESC sensor interference criterion would allow for a reduction in the whisper zones around the sensors in which CBRS operations are curtailed to avoid causing co-channel interference to the sensor.

In essence, improving the immunity of the radars to interference caused by broadband signals has multiple benefits for reducing the occurrence of unnecessary disruptions to CBRS operations. But the benefits of improved interference immunity go beyond CBRS. Currently, operators are bidding billions of dollars to obtain licenses in the new 3.45 GHz band, a band that, while quite valuable, is made less so by the existence of CPAs and PUAs that limit the extent to which broadband systems can use it. Those CPAs and PUAs exist in part to protect DoD radar systems that operate in various areas around the country. Improving the interference immunity of those systems will improve the utility of the 3.45 GHz band overall, especially by reducing the amount of area over which users are potentially precluded from using the band due to the need to protect DoD radars. Improved interference immunity will result in shrinking the geographic areas impacted. by CPAs and PUAs.

Finally, while details of the use of the 3100–3450 MHz band have yet to be determined, it is known that the band is heavily used by DoD radars already, and even more so when some of those radars are relocated out of 3450–3550 MHz to accommodate the 3.45 GHz Service. As with the 3.45 GHz band, improvements in interference immunity of radars operating in the band will only improve the ability to share the band with other systems, such as broadband.

IV. Machine Learning and the 3 GHz Band

There have been many advances in cognitive radar (CR) and machine learning to increase radar performance since the influential papers written by Haykin and Greco [4][5] . Most notably, there has been a recent focus on better sharing and utilization of the electromagnetic spectrum [6]. Works using metacognition combining disparate CR techniques to increase performance in congested electromagnetic environments, which more effectively adapt to changing scenarios show promise to increase radar performance [7]. A metacognition engine (ME) uses reinforcement leaning to detect and forecast bands not in use [17, 18]. To assure the ME does not consider misleading data, autoencoder neural network anomaly filters can be used [19].

Flexibility in switching among bands requires system reconfiguration. This can be done in an array using the Artificially Intelligent Power Amplifier Array (AIPAA) [20]. For generation of simultaneous communication and radar arrays, strong interference beams at undesired angles can emerge. This problem can also be mitigated by the AIPPA. Reconfiguration can be accelerated by application of a generative adversarial network (GAN) [21].

These and other applications of machine learning are promising but have not yet been reduced to practice.

V. Conclusions

The U.S. 3 GHz band is an ideal (if challenging) environment in which to research, develop, and implement methods to improve sharing between radar and broadband systems. Improvements in radar detection algorithms, particularly in the presence of interference and noise, will reduce false detections and the resultant unnecessary disruptions to operations in CBRS. Improving interference immunity of radar systems will not only help such radar systems operate better in the presence of co-channel interference from CBRS, but can also make such systems less susceptible to interference caused by the new 3.45 GHz Service and potentially other new services in bands below 3.45 GHz. Ultimately, it will also make such radar systems perform better in contested electromagnetic environments.

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