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EMERGING MID-BAND RADAR SPECTRUM SHARING (EMBRSS) FEASIBILITY ASSESSMENT REPORT

September 2023

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FORWARD

This reports reflects completion of Department of Defense (DoD or Department) requirements under Section 90008(b)(1)(A) of the Infrastructure Investment and Jobs Act (IIJA) to conduct: "research and development, engineering studies, economic analyses, activities with respect to systems, or other planning activities to improve efficiency and effectiveness of the spectrum use of the Department of Defense in order to make available electromagnetic spectrum in the [3100-3450 MHz] band: (i) for reallocation for shared Federal and non-Federal commercial licensed use; and (ii) for auction under paragraph (3) of this subsection." [1] This report summarizes the findings of those assessments and concludes that shared Federal and non-Federal use of the 3100-3450 MHz band for shared Federal and non-Federal use is feasible if, and only if, the listed conditions enumerated in **Section 8.4** of this report are fully proven through rigorous, in-depth, real-world full scope operational testing with Joint Force assets and implemented in advance of any auction.

This report will be transmitted to the Secretary of Commerce pursuant to Section 90008(b)(1)(C). The Secretary of Commerce shall determine "which frequencies of electromagnetic spectrum in the covered band could be made available on a shared basis between Federal use and non-Federal commercial licensed use, subject to flexible-use service rules" pursuant to Section 90008(b)(2)(A)(i).

When the Secretary of Commerce makes such a determination, this report **does not** reflect the Secretary of Defense's required determination "that sharing those frequencies with non-Federal users would not impact the primary mission of military spectrum users in the covered band" pursuant to Section 90008(b)(2)(B).

[1] Infrastructure Investment and Jobs Act (IIJA), Pub. L. No. 117-58, 135 Stat. 1348-1350 (November 15, 2021), https://www.congress.gov/117/plaws/publ58/PLAW-117publ58.pdf.

EXECUTIVE SUMMARY

OVERVIEW

- After 20 months of extensive collaboration and analysis, the Department of Defense (DoD) completed the Emerging Mid-Band Radar Spectrum Sharing (EMBRSS) feasibility assessment, which examined the feasibility of sharing in the 3100-3450 MHz band (the "band or covered band") between Federal and commercial systems in accordance with the Infrastructure Investment and Jobs Act (IIJA).
- Embracing a **multistakeholder approach**, the **scientific and evidence-based analysis** reflected in the report was supported by unprecedented collaboration between government, industry, and academia.
- The feasibility assessment found **spectrum sharing in the band is not feasible, unless the conditions in the Findings below (and Section 8.4 of the report) are met and any proposed sharing framework is fully proven through rigorous, in-depth, real-world full scope operational testing** with Joint Force assets and implemented in advance of any auction.

BACKGROUND

- DoD uses the spectrum in the covered band extensively for critical homeland defense and other operational missions; these capabilities depend on constant, reliable spectrum access to face current and future threats to the United States.
- DoD operates hundreds of systems in the band, covering the entire United States, across the globe. In addition to the military, the Department of Homeland Security (DHS), National Aeronautics and Space Administration (NASA), and the Defense Industrial Base (DIB) rely on this spectrum for their missions.
- The 3100-3450 MHz band is already congested due to the compression of DoD systems out of the 3450-3550 MHz spectrum band as a result of the 2021 Americas Mid Band Initiative Team (AMBIT) auction.
- As multiple DoD leaders have testified before Congress, proposals for DoD to vacate the 3100-3450 MHz band may result in setting the DoD back several decades compared to near peer adversary nations, take decades, and result in significant financial costs, up to hundreds of billions of dollars.
- Domestic and international spectrum policy decisions must ensure DoD retains the spectrum access it needs to avoid unacceptable operational risk to military capabilities.

A MULTISTAKEHOLDER APPROACH

- DoD established the Partnering to Advance Trusted and Holistic Spectrum Solutions Task Group (PATHSS TG), co-chaired by DoD, the National Telecommunications and Information Administration (NTIA), and industry. A first-of-its kind initiative, the PATHSS Task Group enabled robust collaboration across government, industry, and academia.
  - Embracing a consensus-based, multistakeholder approach, participation consisted of over 200 members from over 60 organizations. Industry representatives included technical advisors and leaders, including C-suite officers from small/medium-sized businesses and Senior Vice Presidents from publicly traded companies, from across the DIB, the information and communications technology sector, and more.
  - To promote maximum transparency, the PATHSS TG included a cleared subgroup at the "secret level" (PATHSS-Classified or PATHSS-C).
- DoD also coordinated across the Federal government, collaborating with the Federal Communications Commission, the Department of Commerce, NTIA, DHS, and NASA, as well as across the Department of Defense, including with the Joint Staff, the Military Departments, and the Combatant Commands.
- The PATHSS TG enabled consideration of a **whole-of-nation view** for increasing the efficiency and effective spectrum use in the 3100-3450 MHz band. Specifically, the PATHSS TG proposed Courses of Action for spectrum sharing in the 3100-3450 MHz band, and actively participated in and validated the analysis presented in the report.

SCIENTIFIC & EVIDENCE-BASED ANALYSIS

- The feasibility assessment considered if Federal and non-Federal users could share (or co-exist) in the band after examining the impact of commercial 5G on U.S. Government radars (one-way analysis), including systems from across DoD, DHS, and NASA.
- Over the course of thousands of hours of rigorous, **scientific, and evidence-based analysis**, the assessment examined over 100 different ground-based, airborne, and shipborne systems in the band, and considered the technical, operational, and programmatic impacts of proposed sharing solutions.

  - Analysis was conducted on 16 priority systems, representative of three operating environments (ground-based, airborne, and shipborne), and sufficient to inform spectrum sharing with all Federal systems across the entire 3100-3450 MHz band.
- The assessment confirmed commercial 5G systems cannot operate within the same frequency band at the same time as government systems without unacceptably degrading critical government mission functions.
- Fixed geographic separation zones and frequency separation are insufficient to enable spectrum sharing. A framework that facilitates spectrum sharing in the time domain to mitigate interference when and where government systems operate presents the only potential means to maximize availability of spectrum for commercial operations when government systems are not active in the band, but the framework must be fully proven and implemented prior to any auction.
- NTIA informed and validated this analysis. DHS and NASA have reviewed and concur with this report.

FINDINGS

- Developing **a capability for large-scale dynamic spectrum sharing (DSS)**, including a dynamic spectrum management system (DSMS) operated by and within the DoD, that evolves the implementation of Citizens Broadband Radio Service (CBRS) in the 3550-3700 MHz band, presents a potential spectrum sharing framework between the Federal and commercial systems in the covered band, but must be proven through rigorous, in-depth, real-world full scope operational testing with Joint Force assets.
- Sharing of the 3100-3450 MHz band between Federal and commercial systems is not feasible unless certain regulatory, technological, and resourcing conditions are proven and implemented. A coordination framework must facilitate spectrum sharing in the time, frequency, and geography domains as well as **stringent adherence** to all the following conditions:
  - DoD retains regulatory primacy
  - Maintain national emergency preemption policy
  - Expand and improve existing CBRS sharing framework policy and technology **(DSS capability)**
  - Government is not liable for damages to commercial systems
  - Address information/operational/cyber security
  - The Defense Industrial Base retains band access for testing and experimentation
  - Current and future Federal systems accommodated equally
  - Establish interference safeguards
  - Address resource requirements
- Even with the above framework and conditions, spectrum sharing between Federal and non-Federal users in the 3100-3450 MHz band will remain challenging. DoD is concerned about the high possibility that non-Federal users will not adhere to the established coordination conditions at all times; the impacts related to airborne systems, due to their range and speed; and required upgrades to multiple classes of ships. **Developing a DSS capability presents a massive engineering challenge.**

CONCLUSION

- This report reflects completion of DoD's requirements in Section 90008(b)(1)(A) of the IIJA for DoD to conduct: "research and development, engineering studies, economic analyses, activities with respect to systems, or other planning activities to improve efficiency and effectiveness of the spectrum use of the Department of Defense in order to make available electromagnetic spectrum in the covered band: (i) for reallocation for shared Federal and non-Federal commercial licensed use; and (ii) for auction."
- This report will be transmitted to the Secretary of Commerce pursuant to Section 90008(b)(1)(C) of the IIJA. The Secretary of Commerce shall determine which frequencies "in the covered band could be made available on a shared basis between Federal use and non-Federal commercial licensed use, subject to flexible-use service rules."
- The Secretary of Commerce may determine frequencies to auction "only if the Secretary of Defense has determined that sharing those frequencies with non-Federal users would not impact the primary mission of military spectrum users in the covered band."
- The completion of this report does **not** automatically result in sharing the 350 MHz of spectrum in this band; additional steps are required by the Secretary of Commerce, and subject to a determination by the Secretary of Defense that spectrum sharing will not impact the primary mission of military spectrum users. Additional planning activities may be required, including those related to the validation and implementation of the nine conditions in the findings above. Further, use of this spectrum is dependent on promulgation of service rules by FCC as part of future public rulemakings.
- Beyond the scope of the IIJA and the EMBRSS Feasibility Assessment, DoD remains committed to spectrum sharing and coexistence for the benefit of the entire Nation and all stakeholders.

ROAD TO SHARING

DoD Milestone 1

Submission of the EMBRSS 3100-3450 MHz study to Secretary of Commerce

- DoD completes sharing study of 3100-3450 MHz pursuant to Section 90008 of IIJA
- DoD submits report on Sept 30 – does not include a **DETERMINATION**
- **FINDINGS:** Sharing not feasible unless certain conditions are met

DoD Milestone 2

Secretary of Commerce proposes identification of 3100-3450 MHz

- In accordance with study findings under Section 90008 (b)(2)(A) **"subject to coordination" with Secretary of Defense**, Office of Science & Technology Policy, congressional committees
- Secretary of Commerce "shall determine" which frequencies could be made available

DoD Milestone 3

Secretary of Defense **DETERMINATION** that sharing will not impact primary mission of military users

- Secretary of Commerce may identify frequencies **only if Secretary of Defense has made determination** about military impact
- **Determination** based on proposed identification

DoD Milestone 4

Secretary of Commerce identifies band after receiving Secretary of Defense's determination of no impact

DoD Milestone 5

DoD develops Transition Plan of implementation details eight months prior to auction

- Implementation consistent with Commercial Spectrum Enhancement Act
- FCC must notify NTIA 18 months in advance of auction start date
- If auction does not reach 110% of sharing costs, is not finalized*

- Milestone 2 is contingent on Milestone 1
- Milestone 4 is contingent on Milestone 3

*Commercial Spectrum Enhancement Act, Pub. L. No. 108-494, 118 Stat. 3986, Title II (2004) (codified in various sections of Title 47 of the United States Code) ("CSEA").

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CHAPTER 1: INTRODUCTION & BACKGROUND

1.1 Introduction

The Department of Defense (DoD or Department) completed the Emerging Mid-Band Radar Spectrum Sharing (EMBRSS) Feasibility Assessment on the 3100-3450 MHZ band (the "band" or "covered band") to conduct sharing and planning activities regarding this important mid-band spectrum range, in accordance with the Infrastructure Investment and Jobs Act (IIJA).[2] In a first-of-its kind collaboration, DoD leveraged the technical expertise of government (including the Federal Communications Commission (FCC), the National Telecommunications and Information Administration (NTIA), and other Federal agencies), industry, and academia in support of these efforts. The report reflects rigorous, scientific, and evidenced-based analysis, informed by industry and academia, and validated by NTIA.[3]

In partnership with the National Spectrum Consortium (NSC), DoD established the Partnering to Advance Trusted and Holistic Spectrum Solutions (PATHSS) Task Group (TG), co-chaired by the Department, NTIA, and industry with the goal of identifying the "realm of the possible" to identify feasible sharing solutions across the 3100-3450 MHz band. DoD's intent in establishing the PATHSS TG was to ensure current and future spectrum decisions result in realistic, collaborative sharing implementations. In this transparent, unprecedented partnership between non-Federal and Federal stakeholders, The PATHSS TG provided opportunities for discussion and sharing of information, and an approach that could be leveraged to inform future sharing opportunities between Federal and non-Federal users. This approach is based on collaboration, full information exchange, and sound technical analysis.

PATHSS TG participation consisted of over 200 members and over 60 companies, including representatives across government, industry, and academia. Industry representatives included technical advisors and senior leaders, including C-suite officers from small and medium-sized businesses as well as Senior Vice Presidents from publicly traded companies.

The 2022 National Defense Strategy (NDS) states the "rapidly evolving features of the security environment threaten to erode the United States' ability to deter aggression and to help maintain favorable balances of power in critical regions" and calls for urgent action to build enduring advantages that "create and sharpen the Joint Force's technological edge." The findings of this feasibility assessment are aligned with the NDS, other DoD strategic objectives, and other national priorities, including maintaining "military overmatch against its adversaries, while

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[2] *Id.*

[3] President Joseph R. Biden, Jr., *Memorandum for the Heads of Executive Departments and Agencies, Subject: Memorandum on Restoring Trust in Government Through Scientific Integrity and Evidence-Based Policymaking,* Washington, DC, January 27, 2021, https://www.whitehouse.gov/briefing-room/presidential-actions/2021/01/27/memorandum-on-restoring-trust-in-government-through-scientific-integrity-and-evidence-based-policymaking/

sharing the spectrum with commercial partners," as reflected in the DoD's 2020 *Electromagnetic Spectrum Superiority Strategy*.[4]

1.2 Background

Military systems operating in this band perform critical national security and homeland defense missions, and represent billions of dollars in investment of taxpayer money; accordingly, viable sharing solutions impact vital national interests.

The feasibility assessment focused on the over 120 different ground-based, shipborne, and airborne radars used by DoD in the 3100-3450 MHz band. DoD employs high-power radar systems in the band for critical national security applications such as long-range air search and surveillance, missile and aircraft surveillance, and associated target tracking applications.[5] NTIA's 2015 *Federal Government Spectrum Use Report* noted all Military Departments employ systems in this band for training and operational use for homeland protection. In addition, the Defense Industrial Base (DIB) and DoD test and evaluation commands use this spectrum for system development and performance verification purposes. As a result, significant strategic, operational, and tactical advantages in combat, training, and technological development would be at risk if DoD lost reliable access to the band. The operational capabilities in this band are necessary to protect our homeland, to respond to emerging threats posed by pacing challenges, and for training warfighters before they deploy overseas. Without access to this band, developmental improvements to these capabilities by DoD research laboratories and the DIB would not be possible, and our homeland and warfighters would be vulnerable to advanced threats.

DoD initiated this feasibility assessment with a commitment to evaluate sharing the 350 MHz in 3100-3450 MHz as part of a whole-of-nation approach, informed by a rigorous assessment to determine optimal sharing methods. This spectrum band is part of a mid-band range of frequencies not only important to the military, but attractive to industry for augmenting advanced wireless services.

1.3 Historical Context

Since at least 2010 U.S. policymakers and industry have considered the repurposing of the band from 3100-3650 MHz for commercial wireless broadband access. Initial inquiries focused on sharing, given the long timelines and mission implications of relocation, and on the upper 100 MHz portion of this range.

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[4] DoD, *Electromagnetic Spectrum Superiority Strategy* (October 2020), https://media.defense.gov/2020/Oct/29/2002525927/-1/-1/0/electromagnetic_spectrum_superiority_strategy.pdf.

[5] Department of Commerce, National Telecommunications and Information Administration, *Federal Government Spectrum Use Reports 225 MHz – 7.125 GHz* (December 1, 2015), as amended, https://ntia.gov/page/Federal-government-spectrum-use-reports-225-mhz-7125-ghz.

[redacted]

2010: In 2010, NTIA released a *Plan and Timetable to Make Available 500 Megahertz of Spectrum for Wireless Broadband* (Plan and Timetable), which identified 3100-3500 MHz as an initial candidate band for potential repurposing.[6] The Plan and Timetable laid out a process to evaluate the feasibility of both Federal and non-Federal bands for repurposing and to identify actions to make spectrum available for wireless broadband within a decade. The Plan and Timetable identified a total of more than 2200 megahertz of Federal and non-Federal spectrum that provide opportunities for wireless broadband to meet a national goal of making 500 megahertz available for commercial use. The Plan and Timetable noted the "important opportunity for Federal agencies to carry out [the] commitment to broadband and economic growth for America by improving the efficiency of their own use of the radio spectrum."[7] According to the Plan and Timetable: "[f]or America to continue to lead the wireless revolution, we must put spectrum to its most effective uses."

NTIA also conducted a "fast track" assessment (Fast Track Report) of accommodating wireless broadband systems in five bands, including 3500-3650 MHz, to recommend spectrum that could be made available in the short term (e.g., 5 years).[8] As part of the Fast Track Report, NTIA recommended only the upper 100 megahertz (3550-3650 MHz) of the 3100-3650 MHz range be made available for use outside of certain coastal and test and training areas. That effort led to the establishment of the FCC's Citizens Broadband Radio Service (CBRS). NTIA selected the 3500-3650 MHz band because Worldwide Interoperability for Microwave Access (WiMAX) equipment had been developed for this segment and it was allocated for the fixed service in portions of the world. The Fast Track Report cited an NTIA review of its frequency assignment and spectrum certification databases, which determined that existing Federal operations left much of the country "sparsely occupied by spectrum activity." NTIA noted this segment was used primarily for high-power shipborne radars.

The Fast Track Report was limited to examining "the potential for geographic sharing approaches for decision by October 1 [2010]. Consideration of relocating these radars to other bands would require technology feasibility studies and comparable spectrum band identification would be required. Even if a comparable band could be found and the technology could be altered to achieve the same technical results, with comparable mission capabilities performance, relocation would still not be possible in five years. Therefore, NTIA focused its examination of this band on geographic sharing."

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[6] Department of Commerce, National Telecommunications and Information Administration, *Plan and Timetable to Make Available 500 Megahertz of Spectrum for Wireless Broadband* (October 2010), https://ntia.gov/files/ntia/publications/tenyearplan_11152010.pdf.

[7] *Id*.

[8] Department of Commerce, National Telecommunications and Information Administration, *An Assessment of the Near-Term Viability of Accommodating Wireless Broadband Systems in the 1675-1710 MHz, 1755-1780 MHz, 3500-3650 MHz, and 4200-4220 MHz, 4380-4400 MHz Bands* (October 2010), https://ntia.gov/files/ntia/publications/fasttrackevaluation_11152010.pdf.

[redacted]

[redacted]

2015: In 2015, the FCC adopted rules for shared commercial use of the 3550-3700 MHz band. The CBRS rules in 47 CFR Part 96 created a three-tiered access and authorization framework to accommodate shared Federal and non-Federal use.[9] Citing the Fast Track Report, the FCC's *Amendment of the Commission's Rules with Regard to Commercial Operations in the 3550-3650 MHz Band: Report and Order and Second Further Notice of Proposed Rulemaking* found that NTIA's initial analysis showed that large exclusion zones would be required to protect DoD radar systems.[10] A 2014 FCC Further Notice of Proposed Rulemaking sought comment on the Fast Track exclusion zones and highlighted discussions among DoD and other agencies to reevaluate the zones.

NTIA's *Federal Spectrum Use Reports* (2015) indicated the intensity of DoD's radar system use in the 3100-3300 MHz and 3300-3450 MHz segments, respectively. For 3100-3300 MHz, the compendium described DoD employment of radar systems for "critical national security applications such as long-range air search and surveillance radars, missile and aircraft surveillance radars, and associated radar target tracking applications."[11] NTIA noted DoD "expects to increase use of the 3100-3300 MHz band in the future. The Navy has plans for radar systems, operating on frequencies including in this band, to be used on the next generation destroyers." For 3300-3500 MHz, the compendium cited DoD employment of radar systems for "critical national security applications such as long-range air search and surveillance radars, missile and aircraft surveillance radars, and associated radar target tracking applications. The U.S. Government (USG) has invested billions of dollars in these systems." For both segments, NTIA anticipated DoD spectrum requirements to support these systems as increasing and continuing "for the foreseeable future."[12]

The final framework reduced the geographic area of the zones by approximately 77 percent and included NTIA's recommendation of the use of sensor technology. This Federal/non-Federal sharing arrangement is part of a broader three-tiered sharing framework enabled by a Spectrum Access System (SAS). As incumbent users, DoD radar capabilities represent the highest tier in this framework and receive interference protection from CBRS users. The two tiers, Priority Access and General Authorized Access (GAA) may be authorized in any given location and frequency by a SAS. Priority Access operations receive protection from GAA operations. In implementing this framework, the FCC added primary fixed and mobile except aeronautical mobile allocations to the 3550-3650 MHz band in the non-Federal table. The Commission

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[9] Federal Communications Commission, *Amendment of the Commission's Rules with Regard to Commercial Operations in the 3550-3650 MHz Band: Report and Order and Second Further Notice of Proposed Rulemaking*, 30 FCC Rcd 3959 (5) (April 21, 2015), https://docs.fcc.gov/public/attachments/FCC-15-47A1.pdf.

[10] *Id*.

[11] Department of Commerce, National Telecommunications and Information Administration, *Federal Government Spectrum Use Reports 225 MHz – 7.125 GHz* (December 1, 2015), as amended, https://ntia.gov/page/Federal-government-spectrum-use-reports-225-mhz-7125-ghz

[12] *Id*.

[redacted]

removed the non-Federal radiolocation allocation and reached an agreement with NTIA on continued Federal use of airborne radars in the band segment.

2016: In 2016, NTIA released information from a Quantitative Assessment of five bands, including 3100-3550 MHz.[13] Drawing from information requested by NTIA from Federal agencies, the assessment concluded that total spectrum usage is much less in the 3505-3550 MHz segment as compared to the rest of the band: "This indicates that an opportunity exists to examine the possibility of sharing with wireless broadband." The NTIA assessment noted that as experience with database forms of sharing is gained with CBRS, this model "potentially could be implemented in portions of the 3100-3550 MHz band for wireless broadband. Any sharing feasibility studies would also include consideration of airborne systems that operate in the frequency band."

2018: In 2018, the Making Opportunities for Broadband Investment and Limiting Excessive and Needless Obstacles to Wireless (MOBILE NOW) Act directed the Secretary of Commerce, in consultation with the FCC and each affected agency, to report to Congress and the FCC on "the feasibility of allowing commercial wireless services, licensed or unlicensed, to share" 3100-3550 MHz.[14] Congress requested an assessment of possible impacts of sharing on Federal and non-Federal users operating in the band and the "criteria that may be necessary to ensure shared licensed or unlicensed services would not cause harmful interference" to incumbent Federal or non-Federal users. MOBILE NOW directed, if sharing is determined to be feasible, an identification of which frequencies are most suitable for sharing with commercial wireless services, via auction or unlicensed use or a combination.[15]

NTIA evaluated the feasibility of allowing commercial wireless services, on both a licensed and unlicensed basis, to share use of the radio frequency (RF) spectrum at 3100-3550 MHz, under the assumption of no changes in incumbent operations, except for possibly limiting some use of airborne radar systems over the Continental United States (CONUS).[16]

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[13] Department of Commerce, National Telecommunications and Information Administration, *Quantitative Assessments of Spectrum Usage* (November 17, 2016), https://www.ntia.gov/report/2016/quantitative-assessments-spectrum-usage. *Note*, NTIA's plan for *Quantitative Assessments of Spectrum Usage* focused on the evaluation of existing use in 960 megahertz of spectrum in five bands previously identified for potential future sharing studies: 1300-1390 MHz, 1675-1695 MHz, 2700-2900 MHz, 2900-3100 MHz, and 3100-3550 MHz. Agencies were asked to verify system characteristics associated with their frequency assignments to enable calculation of the geographic coverage area used by these systems.

[14] Consolidate Appropriations Act of 2018 (MOBILE NOW Act), P.L. 115-141 (2018), https://www.congress.gov/115/plaws/publ141/PLAW-115publ141.pdf.

[15] *Id*.

[16] National Telecommunications and Information Administration, *Feasibility of Commercial Wireless Services Sharing with Federal Operations in the 3100-3550 MHz Band* (July 2020),

This report reached two principal conclusions based on the assumption of no changes in incumbent operations and the legislative mandate to consider sharing. First, the 3450-3550 MHz portion of this band demonstrated potential for sharing, including at the commercial system power levels sought by industry. Second, although some sharing of spectrum below 3450 MHz may be possible, additional analysis of the entire band should be conducted to assess the various sharing mechanisms and the potential for relocating incumbents from some portion of the remainder of the band for commercial use. Currently, both classified and unclassified Federal systems operated below 3450 MHz, which could pose challenges to sharing with a commercial wireless system. Further, potential exists for even more congestion if some Federal operations are shifted down from above 3450 MHz to accommodate sharing at 3450-3550 MHz. These circumstances prompted additional considerations reflected in this feasibility assessment.

2020: NTIA's July 2020 report indicated it selected the 3450-3550 MHz band to study for potential sharing between Federal systems and a variety of non-Federal commercial wireless operations. NTIA worked with DoD to evaluate conditions needed to enable commercial services to operate without causing impact to incumbent operations. The report indicated "that commercial operations would impact incumbent Federal systems; however, spectrum sharing that provides both sufficient protection to incumbent operations and an attractive commercial business case may be possible with further information and analysis, including studying the efficacy of deploying appropriate time-based sharing mechanisms."[17]

Following the NTIA assessment, the 2020 America's Mid-Band Initiative Team (AMBIT) report set an objective to make 100 megahertz of contiguous spectrum available in the 3400-3550 MHz band at full commercial power across the largest feasible CONUS geographic area by revising DoD operations or other means. Early analysis informed a decision that identified the 3450-3550 MHz band as the most suitable band to provide the 100 megahertz of continuous spectrum. The solution determined by AMBIT focused on compression as a means of enabling commercial access as part of the FCC's auction. The report noted: "With this plan, DoD has accepted risk to make this spectrum available. To ensure effective and timely 5G network deployment, DoD requires funding for mid- and long-term efforts to implement CONOPS changes, conduct analyses to mitigate the effects of operating in less spectrum, and conduct the necessary research and development (R&D) to modify equipment, as necessary, in 100 MHz of less spectrum."

In part, the AMBIT report described early decisions by the White House Office of Science and Technology Policy (OSTP) and the DoD Steering Group members for solution development:

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https://www.ntia.doc.gov/sites/default/files/publications/ntia_3100-3550_mhz_mobile_now_report_to_congress_0.pdf.

[17] NTIA's *Feasibility of Commercial Wireless Services Sharing with Federal Operations in the 3100-3550 MHz Band* report added that, "If more work was done on the mechanisms for time-based sharing, the report could reach a more definitive conclusion regarding their technical feasibility. To protect shipborne systems, it may be technically feasible to use an approach similar to that used in the CBRS band to detect the presence of transmissions from a Federal system."

[redacted]

"The first and most important decision was to isolate the 100 MHz to the 3450-3550 MHz band instead of the 3400-3450 MHz band. This decision removed Airborne Warning and Control Systems (AWACS) and several ground radars from analysis. It also reduced the impact to electromagnetic warfare (EW) ranges and avoids further compounding anticipated compression problems for radar-to-radar spectrum deconfliction, that still require remediation. The second decision was to define the area of consideration as the contiguous U.S., as opposed to the CONUS. Isolating the lower 48 contiguous states removed a critical capability of the Missile Defense Agency (MDA) from the analysis."

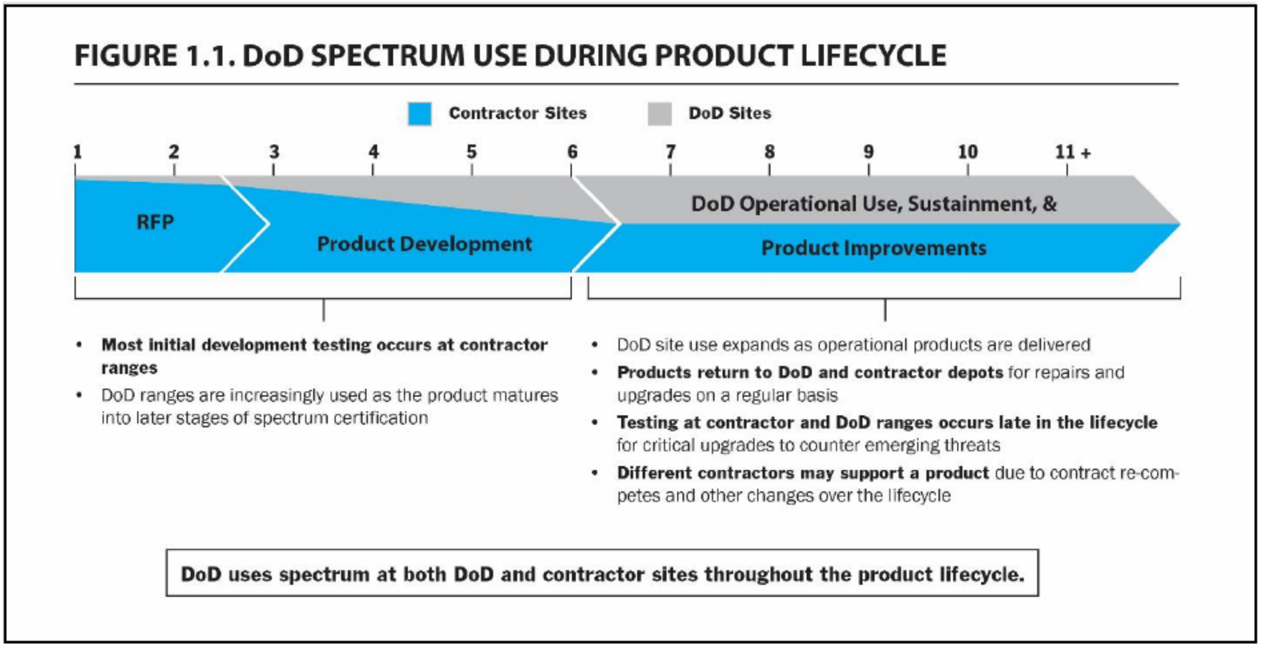

Figure 1.1: DoD Spectrum Use During Product Lifecycle

1.4 Statutory Context

The EMBRSS feasibility assessment was guided by Section 90008 of the IIJA.[18]

1.5 Key Factors

- **Operational Context**: The unique spectrum characteristics of 3100-3450 MHz provide long detection ranges, tracking accuracy, and discrimination capability required for DoD radar systems. The band is low enough in the frequency range to maintain a high-power aperture capability in a transportable system. This characteristic enables medium- and long-range search capabilities for military targets. This band is also high enough in the frequency range that a sufficient angular accuracy can be maintained for a radar track function for a fire control capability. Historically, this has been one of only two bands that provide for the development of military radars that have small enough antenna

[18] Infrastructure Investment and Jobs Act, Pub. L. No. 117-58, § 90008 (2021). https://www.congress.gov/bill/117th-congress/house-bill/3684/text

[redacted]

apertures to be mobile but sufficient range capabilities to serve as medium- and long-range radars.

- **Implications of the 3450-3550 MHz Auction**: DoD operations in 3100-3450 MHz are significantly more complex, intensive, and spread across a greater geographic area compared to other portions of the 3 GHz range. This complexity was increased by compressing existing DoD operations in the 3450-3550 MHz band to operate below 3450 MHz in order to make the 3450-3550 MHz band available for maximum commercial usage as part of the previously cited FCC auction.

- **Sharing as Way Forward**: DoD remains focused on sharing solutions. DoD has demonstrated a commitment of reaching sharing solutions that work for the nation without compromising DoD's mission. According to recent Congressional testimony from the DoD Chief Information Officer: "Our efforts build on previous sharing initiatives led by the Department. We are committed to helping maximize U.S. 5G and Next G dominance while also ensuring that the Joint Force can both train and conduct operations in and near the continental U.S. where use of terrestrial, airborne, and sea-based radars operating in the mid-band are critical for success."[19]

  This feasibility assessment was informed by the definition of sharing under DoD policy, which is that DoD components shall consider sharing spectrum with other Federal agencies and with commercial users. DoD policy states, "Sharing of spectrum shall be accomplished: (1) Without degradation to the DoD mission, (2) In a manner that provides current and future DoD users with sufficient regulatory protection, [and] (3) With minimal risk that such sharing will result in loss of access to the spectrum necessary to perform the DoD mission."[20] This policy guided DoD's approach to the assessment of 3100-3450 MHz and establishes that spectrum sharing **does not** involve reallocation or vacation of the band by incumbent users.

- **Importance of Partnerships**: Collaboration between government, industry, and academia was integral to the EMBRSS effort, as further described in Chapter 3. Engagement with industry is a vital part of this ground-breaking effort. Lessons learned from the AMBIT effort, which identified the viability of the 3450-3550 MHz spectrum band for auction, highlighted the risks of compressed timelines for undertaking Federal spectrum repurposing studies, including insufficient time for industry outreach. DoD was

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[19] *U.S. Congress, House Armed Services Committee, Department of Defense Information Technology, Cybersecurity, and Information Assurance for Fiscal Year 2023*, *Before the House Armed Services Subcommittee on Cyber, Innovative Technologies, and Information Systems,* 117th Cong., 2nd sess., May 18, 2022, 8, (Statement of Honorable John B. Sherman, DoD CIO) *https://democrats-armedservices.house.gov/?A=Files.Serve&File_id=71C0F90C-EA61-4F87-ABCA-BB19B7DAAC7D*.

[20] DoD Instruction 4650.01, "Policy and Procedures for Management and Use of the Electromagnetic Spectrum," January 9, 2009, as amended, https://www.esd.whs.mil/portals/54/documents/dd/issuances/dodi/465001p.pdf.

committed to further closing the between government and industry in this feasibility assessment. The feasibility assessment employed modeling capabilities, databases, and supporting assumptions accepted by government and industry stakeholders as standards to conduct electromagnetic spectrum compatibility analyses of the sharing use cases.

- **Transparency**: Building trust between industry and DoD has also been an important element of the feasibility assessment. DoD's innovative approach for breaking from the status quo to achieve this objective--including ensuring broad participation from industry, government, and academia, transparent processes, and enhanced information sharing--is further described in Chapter 3.

- **Domestic and International Policy Considerations**: Domestic and international spectrum policy decisions must ensure DoD retains the spectrum access it needs to avoid unacceptable operational risk to military capabilities.

1.6 Courses of Action

Working with government, industry, and academia, DoD pursued a Courses of Action (COAs) framework to assess the feasibility of spectrum sharing architectures, further described in **Chapters 3 and 7**.

CHAPTER 2: OVERVIEW OF THE 3100-3450 MHZ BAND RANGE

2.1 Introduction

The 3100-3450 MHz spectrum range is critically import to DoD missions, including homeland defense, as discussed throughout this report. The following section provides an overview of domestic and international allocation in the band and addresses the importance of this band to military and other Federal missions. This section also summarizes the unique physics and propagation characteristics of this band that have driven billions of dollars in investments for military capabilities over the last several decades.

2.2 Domestic and International Allocation

Domestic Allocations: The 3100-3450 MHz range is allocated for Federal radiolocation and ground-based radionavigation services on a primary basis in the United States, as shown below.

TABLE 2.1. EXCERPT FROM THE U.S. NATIONAL TABLE OF FREQUENCY ALLOCATIONS		
Frequency Band	**Federal Usage**	**Non-Federal Usage**
3100-3300 MHz	Radiolocation Earth exploration-satellite (active) Space research (active) **G59** (all Federal non-military radiolocation shall be secondary to military radiolocation) Earth exploration-satellite (active) **US343** (all practicable steps shall have been taken to protect the radio astronomy service from harmful interference)	Earth exploration-satellite (active) Space research (active) Radiolocation **US342** (all practicable steps shall be taken to protect the radio astronomy service from harmful interference)
3300-3500 MHz	Radiolocation **US108** (low-power survey operations secondary to other Federal radiolocation operations) **G2** (use of the Federal radiolocation service is restricted to the military services)	Amateur Radiolocation **5.282** (amateur-satellite service on a non-interference basis) **US108** (low-power survey operations secondary to Federal radiolocation operations)

Table 2.1: Excerpt from the U.S. National Table of Frequency Allocations

The entire range is allocated for Federal and non-Federal radiolocation services. Non-Federal users operate on a secondary basis to primary Federal radiolocation services in the 3100-3450 MHz band.[21]

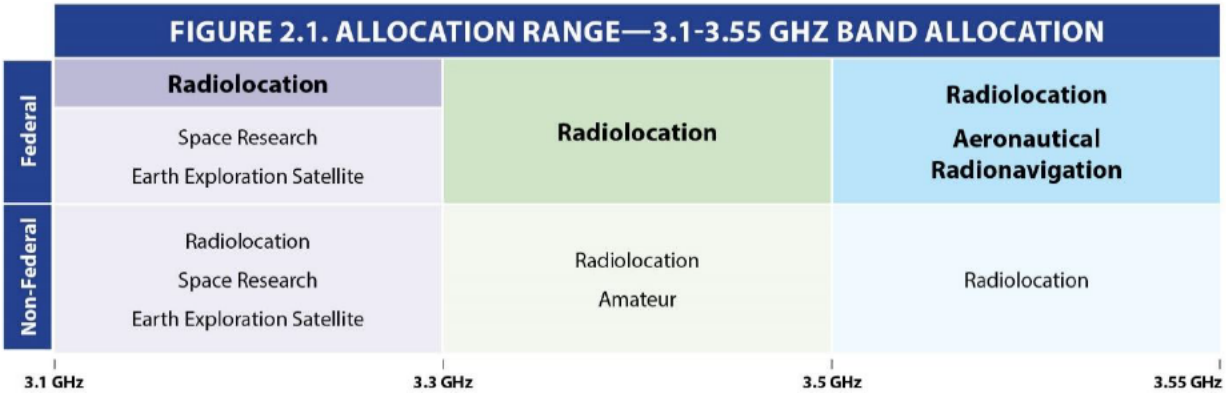

Figure 2.1: Allocation Range – 3100-3550 MHz Band Allocation

International Allocations: Military radars operate across a tuning range in the 2700-3600 MHz (see Rec. ITU-R M.1464 and M.1465), which is allocated to the radiolocation service in the Radio Regulations International Table of Allocations. In the International Table of Allocations, 3100-3300 MHz is allocated to primary radiolocation use in all three International Telecommunication Union (ITU) regions. In 3300-3400 MHz, each ITU Region has radiolocation as primary, with Region 2 having secondary allocations for amateur, fixed and mobile, and Region 3 having a secondary allocation for amateur. In addition, in Region 2, in 13 countries (including Mexico), the band is allocated to the mobile service on a primary basis as well as identified for International Mobile Telecommunications (IMT) or 5G, via footnotes No. 5.429C and No. 5.429D. This band is also identified for IMT in over 30 countries in the Middle East and Africa, as well as several more in the Asia Pacific. These identifications were established at the 2015 World Radiocommunication Conference (WRC-15), with further movement towards harmonization occurring at WRC-19, and expected to continue at WRC-23 in late 2023. Countries including the United States will consider further global harmonization of the band for IMT use.

In 3400-3500 MHz, Regions 1 (Europe/Africa) and 2 (Americas) have primary allocations to the fixed, mobile and fixed-satellite service, while the mobile service allocation is secondary in Region 3 (Asia), with some exceptions (e.g., Korea, Japan). These mobile allocations are also globally harmonized with identifications for IMT/5G use, including in the United States, where the band 3400-3700 MHz was identified at WRC-15. Footnote No. 5.433 of the Radio Regulations urges all administrations operating radiolocation systems in the 3400-3600 MHz band to cease operations by 1985. Internationally, many government administrations have moved to auction this spectrum for allocation to commercial entities, including for 5G development. Within the 3300-4200 MHz band, numerous countries have allocated such spectrum for

[21] Table of Frequency Allocations, 47 C.F.R. § 2.106 (G59), (2023), https://www.ecfr.gov/current/title-47/chapter-I/subchapter-A/part-2/subpart-B/section-2.106.

commercial use.[22] This range (3 GHz) is part of a standardized Third Generation Partnership Project (3GPP) (also referenced as Digital Cancelation of 5G) band that is harmonized for use in dozens of countries. The frequency bands have also been harmonized in frequency arrangement recommendations in CITEL (Organization of American States - Inter-American Telecommunication Commission) and in the ITU Recommendations on spectrum use.

2.3 Desirable Characteristics of this Band for DoD Radar and Non-Federal System Use

Radio spectrum within the 3100-3450 MHz band is desirable for several reasons, including consideration of the trade-offs among radar performance, such as range and echo rejection, and historical uses of mid-band spectrum. Radiolocation radars operate with a high degree of mutual compatibility with other radars in the band. This is the result of the capability of radar systems to "preferentially detect the echoes of their own transmitters and to reject the low duty cycle pulse of other radars."[23]

Physics and propagation characteristics make this band desirable for radiolocation and enable medium and long-range search for military targets. The band is also high enough in the frequency range that sufficient accurate angular accuracy can be maintained for a radar track function for a fire control capability, as well as ballistic missile and other space-based discrimination for larger radars. Historically, the 3 GHz band has been one of a few bands that provides for the development of military radars with small enough antenna apertures to be mobile, but also sufficient range capabilities to serve as medium and long-range radars. [redacted]

Lower-band frequencies have the capability of traveling longer distances due to their lower path loss when compared with higher frequencies, and have physics and propagation characteristics that allow penetration of obstructions, such as building materials and foliage, with less signal degradation than higher frequencies. Higher-band frequencies have higher path loss, and thus travel shorter distances, but support higher data rates, which can result in higher capacity and increased speeds for data transfer. Mid-band spectrum blends the characteristics of both lower-band and higher-band, offering enhanced geographic coverage and data capacity to increase connectivity and data speeds.[24]

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[22] Accenture, *Spectrum Allocation in the United States* (September 2022), Commissioned by CTIA, https://www.ctia.org/news/spectrum-allocation-in-the-united-states.

[23] U.S. Department of Commerce, National Telecommunications and Information Administration, *Federal Government Spectrum Compendium: 3100-3300 MHz* (December 1, 2015), https://www.ntia.doc.gov/files/ntia/publications/compendium/3100.00-3300.00_01DEC15.pdf.

[24] Accenture, *Spectrum Allocation in the United States* (September 2022), Commissioned by CTIA, https://www.ctia.org/news/spectrum-allocation-in-the-united-states.

2.4 Historical Context

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

2.5 Other Federal Systems

In addition to DoD's reliance on this band, other Federal users also employ their systems in this band.

Under Government footnote G59 in the U.S. Table of Allocations, the 3100-3300 MHz band is among a list of frequency ranges in which all Federal non-military radiolocation shall be secondary to military radiolocation.[25] As a result, there are relatively limited additional non-DoD assignments in this range. According to the 2020 MOBILE NOW report to Congress, Federal allocations, secondary to radiolocation, are for Earth exploration-satellite (active) and space research (active).

DHS operates fixed and transportable systems in this band to track unmanned aerial vehicles (UAVs).[26] DHS operations are limited to fixed and transportable radars. DHS capabilities in the band include multi-function radar which provides protective mission support, counter-fire target acquisition, and border security operations.

Additionally, NASA maintains an experimental frequency assignment at 3200 MHz for the NASA-Indian Space Research Organization (ISRO) Synthetic Aperture Radar (SAR) (NISAR) S-band SAR being developed by the ISRO.[27] Allocations in the 3100-3300 MHz band are among a list of frequency ranges in which all Federal non- military radiolocation shall be secondary to military radiolocation.

Further, in accordance with footnote US342 of the U.S. Table of Frequency Allocations, radio astronomy is "authorized to use the bands 3260-3267 MHz, 3332-3339 MHz, and 3345.8-3352.5 MHz for spectral line observations, and all practicable steps are required to be taken to protect those operations from harmful interference."

NTIA has reported that currently no Federal systems of concern are operating in the Earth exploration-satellite (active) and space research (active) services in the 3100-3300 MHz portion

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[25] Table of Frequency Allocations, 47 C.F.R. § 2.106 (G59), (2023), https://www.law.cornell.edu/cfr/text/47/2.106

[26] Department of Commerce, National Telecommunications and Information Administration, *Feasibility of Commercial Wireless Services Sharing with Federal Operations in the 3100-3550 MHz Band* (July 2020), https://www.ntia.doc.gov/sites/default/files/publications/ntia_3100-3550_mhz_mobile_now_report_to_congress_0.pdf.

[27] *Id*. (*Note,* according to the NTIA *Feasibility of Commercial Wireless Services Sharing with Federal Operations in the 3100-3550 MHz Band* report on MOBILE NOW, this system is using "advanced radar imaging that will provide an unprecedented, detailed view of Earth, the satellite is designed to observe and take measurements of some of the planet's most complex processes. These include ecosystem disturbances, ice-sheet collapse, and natural hazards such as earthquakes, tsunamis, volcanoes and landslides.")

[redacted]

of the band under Government footnote G2, for 3300-3550 MHz, "use of the Federal radiolocation service is restricted to the military services."[28]

2.6 Non-Federal Systems

As of 2020, only eight active non-Federal radiolocation licenses have been issued between 3300 –3500 MHz; these licensees use this spectrum for a range of commercial and industrial radiolocation services.[29] These services operate in this band pursuant to a secondary allocation and must not cause harmful interference to operations such as radio astronomy stations and stations authorized by foreign nations for use in this frequency. These non-Federal radiolocation stations are in the process of vacating this band to the 2900-3000 MHz band.[30] Of note, there are also hundreds of non-Federal experimental licenses that operate within the 3100 – 3550 MHz band. These experimental licenses are issued pursuant to Part 5 of the FCC rules and have been granted for a broad range of research and experimental purposes, to include by the Defense Industrial Base at their facilities in support of Federal contract activities. Services under these experimental licenses must operate on a non-interference basis.[31]

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[28] *Id.*

[29] U.S. Federal Communications Commission, *Facilitating Shared Use in the 3100-3550 MHz Band: Report and Order and Further Notice of Proposed Rulemaking*, WT Docket No. 19-348, 35 FCC Rcd 11078 (13) (October 2, 2020), ¶ 15, https://docs.fcc.gov/public/attachments/FCC-20-138A1.pdf.

[30] *Id.*

[31] Table of Frequency Allocations, 47 C.F.R. § 5.84 (2023), https://www.ecfr.gov/current/title-47/chapter-I/subchapter-A/part-5/subpart-B/section-5.84.

CHAPTER 3: FEASIBILITY ASSESSMENT CONSIDERATIONS

3.1 Introduction

The following section provides an overview of the approach, framework, and governance structures that the Department pursued in carrying out the EMBRSS feasibility assessment. This includes unprecedented and continuing collaboration between government, industry, and academia. This effort report reflects rigorous, scientific, and evidenced-based analysis, informed and validated by industry and government, including NTIA.[32]

Extensive coordination was essential to this complex undertaking. Through this effort, the Department explored a range of proposed COAs to ensure the feasibility assessment covered all reasonable options, subject to DoD's definition of spectrum sharing. However, as is evidenced by the data provided, the feasibility assessment is not conclusive and only meant to assess feasibility. Aligned with the DoD *Electromagnetic Spectrum Superiority Strategy*, the Department remains committed to spectrum sharing as "increased spectrum sharing remains a critical priority for the Department to meet the growing demands for spectrum access for both commerce and DoD" and recognizes "the importance of U.S. wireless leadership to the nation's economic prosperity, and 5G technologies mark a critical pivot for spectrum policy, technology innovation, and national security." [33]

With these strategic imperatives in mind, in partnership with the NSC, DoD established the PATHSS TG to foster trust among stakeholders from government, industry, and academia, and to develop a shared understanding of technology and policy needs.[34] PATHSS demonstrates DoD's commitment to serving as a reliable partner in achieving national spectrum goals and a responsible steward of the spectrum needed to execute DoD's mission. Within the Department, DoD leveraged existing oversight and governance via the EMS Senior Steering Group (SSG) to provide executive-level direction to the feasibility assessment.

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[32] President Joseph R. Biden, Jr., *Memorandum for the Heads of Executive Departments and Agencies, Subject: Memorandum on Restoring Trust in Government Through Scientific Integrity and Evidence-Based Policymaking,* Washington, DC, January 27, 2021, https://www.whitehouse.gov/briefing-room/presidential-actions/2021/01/27/memorandum-on-restoring-trust-in-government-through-scientific-integrity-and-evidence-based-policymaking/

[33] DoD, *Electromagnetic Spectrum Superiority Strategy* (October 2020), at 6, https://media.defense.gov/2020/Oct/29/2002525927/-1/-1/0/electromagnetic_spectrum_superiority_strategy.pdf.

[34] Nichols Martin, "National Spectrum Consortium Creates Task Group for 5G Technology," *Executive Government*, (November 2, 2021), https://executivegov.com/2021/11/national-spectrum-consortium-creates-task-group-for-5g-technology.

> **"This is our effort to reach out [and] hear other voices—not just look at it through a defense prism, but try to balance all the different equities there."**
>
> *— DoD Chief Information Officer John Sherman during his keynote address at the NTIA's Spectrum Policy Symposium in September 2022.*

The PATHSS TG provided a novel and unique model for DoD to examine innovative spectrum sharing solutions—proposed by industry and academic partners—to meet the objectives of the IIJA. In the long term, PATHSS provides an opportunity to plan for extensible technological and policy frameworks for realistic, collaborative spectrum sharing.[35] Through the PATHSS TG, DoD leveraged the technical expertise and innovation of the industry, government, and academia to carry out the feasibility assessment as part of a first-of-its kind collaborative endeavor.

Other lines of effort essential to the feasibility assessment's completion included the DoD-led analytical team and ongoing engagement with key stakeholders through established internal DoD governance structures, including the EMBRSS Ad Hoc Working Group.

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[35] "National Spectrum Consortium Launches PATHSS Task Group to Explore 5G Spectrum Sharing," *Business Wire* (October 27, 2021), https://www.businesswire.com/news/home/20211027005267/en#20211102.

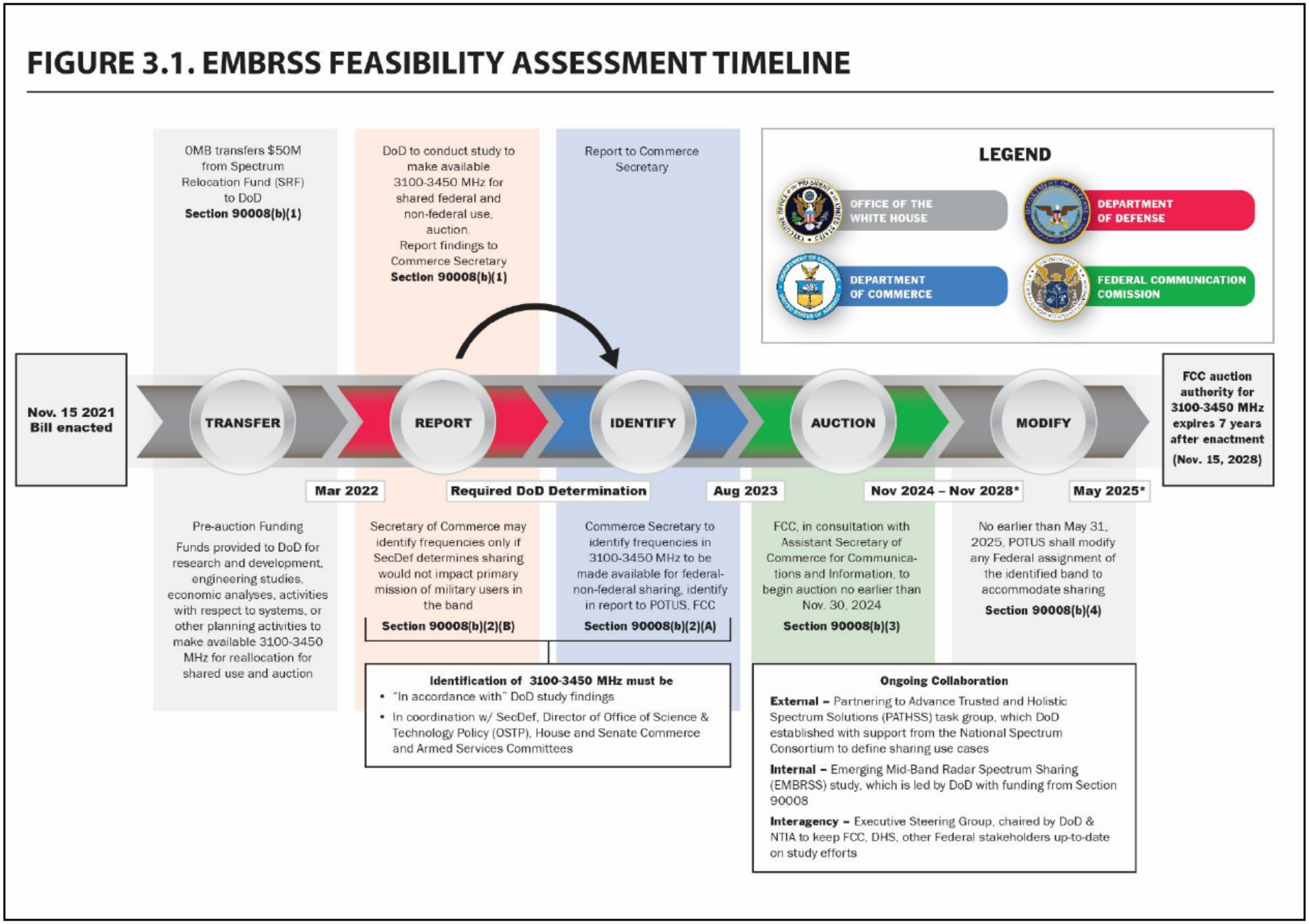


Figure 3.1: EMBRSS Feasibility Assessment Timeline

[redacted]

3.2 Roles and Responsibilities

DoD embraced a multistakeholder approach in conducting the feasibility assessment. Integral to the DoD-led effort, PATHSS TG participants proposed COAs for analysis, subject to DoD's definition of spectrum sharing. These COAs included ideas for spectrum sharing in the 3100-3450 MHz band and served as the basis for the analysis presented in this report. Developing these COAs collaboratively ensured that DoD included comprehensive viewpoints in the analysis of 3100-3450 MHz. PATHSS TG collaboration throughout the feasibility assessment provided technical input and subject-matter expertise.

The EMBRSS Ad Hoc Working Group, the DoD's internal working group, was established to support the feasibility assessment. Membership included representatives from the stakeholder Services and system Program Management Offices (PMOs), which provided support to the EMBRSS technical team.

The EMBRSS Ad Hoc Working Group is part of the governance structure of the DoD EMS SSG, which reports to the DoD Command, Control and Communications Leadership Board (C3LB). This framework establishes transparency, controls, and oversight for the feasibility assessment within the Department, in order to provide decision support to the Deputy Secretary of Defense and Secretary of Defense.

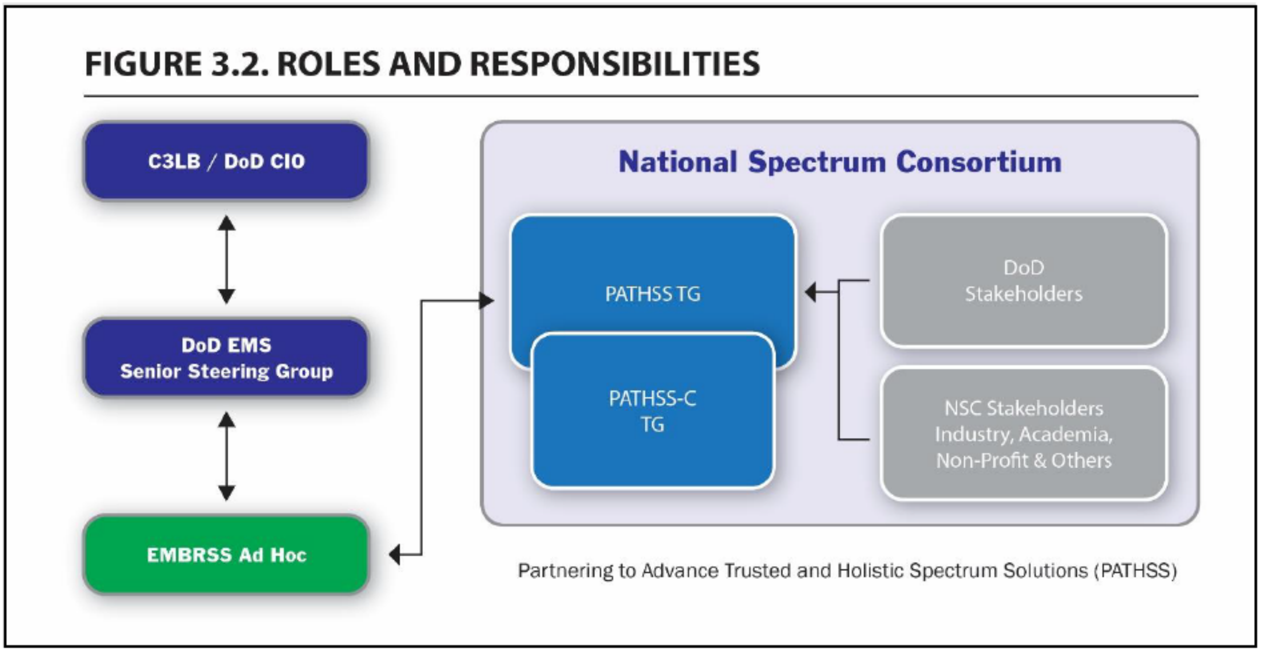


Figure 3.2: Roles and Responsibilities

[redacted]

3.3 Statutory Requirements

This feasibility assessment was conducted in accordance with the requirements of Section 90008 of the Infrastructure Investment and Jobs Act.

3.4 Coordination with Industry

The PATHSS TG was formed in October 2021, and the first meeting was held in November 2021. Although not required by law, DoD collaborated with the NSC in establishing PATHSS to leverage the technical expertise of a cross-section of stakeholders. This collaborative body seeks to identify the realm of the possible regarding sharing solutions to enable commercial use and inform policy and processes, and to create a replicable approach for addressing future sharing scenarios.

The PATHSS TG consists of nearly 200 members and over 60 companies, including representatives each of the following categories.

- Telecommunications service providers
- Cable service providers
- Commercial wireless equipment manufacturers/providers
- Military radar, communications, effector, EW equipment manufacturers, providers, and integrators
- Commercial spectrum users (e.g., companies whose business models depend on spectrum access in lower 3 GHz bands, local government 5G pilot programs, etc.)
- Academia

PATHSS membership is open to all NSC member organizations. Individual participants must register and be verified, in order to have access to Controlled Unclassified Information ([redacted] with need-to-know access.

The PATHSS TG was co-chaired by DoD, NTIA, and industry with the group meeting at least monthly since inception.

PATHSS was designed to build trust between industry and DoD through:

1. Transparent processes with the broadest possible involvement in PATHSS, with expanded access to information (Proprietary and [redacted]
2. Access to industry-proprietary and classified information to a broadly representative sub-group of PATHSS TG members (PATHSS-Classified or PATHSS-C), which collectively offers credible representations back to the broader PATHSS TG;

3. Demonstrated, sustained engagement by senior DoD leadership; and

4. A new mechanism that enables DoD and industry to exchange proprietary, sensitive, and classified information about defense and commercial spectrum operations in order to inform the development of architectures and techniques (Courses of Action (COAs)) in the national regulatory environment.

To provide deeper insight into the technical and operational intricacies of the incumbent military capabilities in 3100-3450 MHz, a subset of the PATHSS TG stakeholders (PATHSS-C) were cleared to receive classified information on specific DoD systems (up to Secret collateral). PATHSS-C consisted of no more than two representatives from each of 25 approved organizations, plus USG representatives. In general, each organization put forth one senior leadership representative and one technical representative. The 25 organizations were drawn from five stakeholder categories (described above).

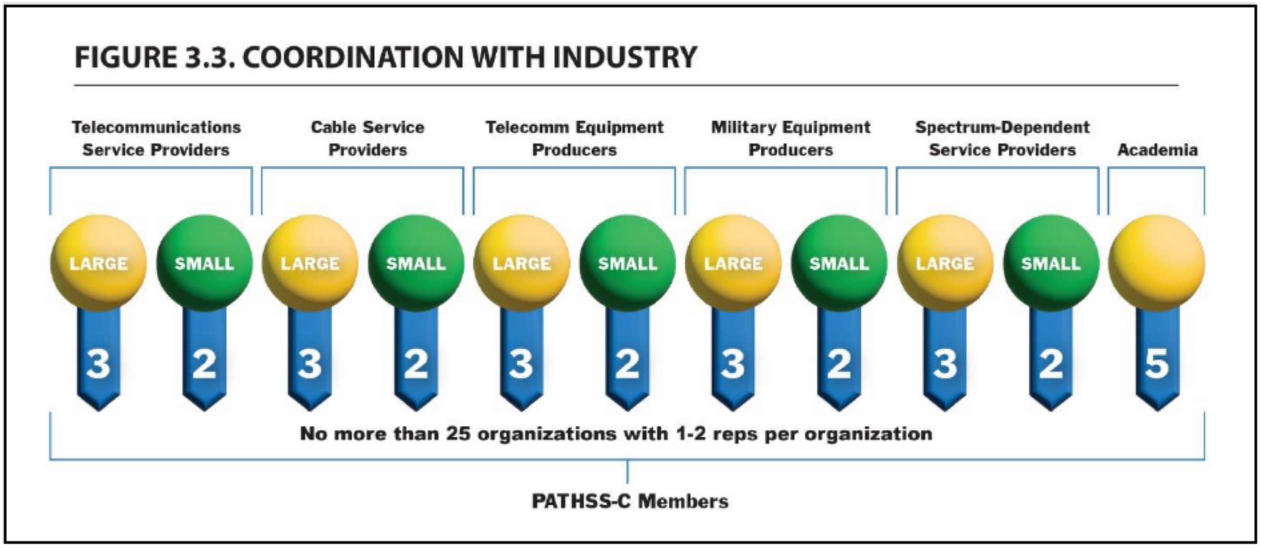


Figure 3.3: Coordination with Industry

3.5 Scope of Work

The PATHSS TG was charged with developing recommendations for spectrum sharing COAs that could meet the anticipated needs of non-Federal stakeholders while preserving the incumbent DoD missions and activities no later than the end of May 2022, with the final product delivered to DoD for in-depth analysis no later than the end of June 2022. The intent was to identify three to five potential COAs for DoD and commercial sharing in the 3100-3450 MHz band. The group was tasked with clearly defining proposals for the COAs and the technical parameters of each, including high power and low power variations, network architectures, intensity and criticality of use, receiver characteristics, and other parameters. For each use case, a framework was addressed under which technical solutions would enable spectrum sharing that would likely meet required commercial and military service levels and performance requirements, as inputs into more detailed, follow-on technical analyses.

Below provides the PATHSS Project Approval Request (PAR):

> *Pursuant to the Infrastructure Investment and Jobs Act, Section 90008, DoD has been directed to 1) improve the efficiency and effectiveness of its use of spectrum in the 3.1-3.45 GHz band and 2) determine how frequencies within this covered band can be reallocated on a shared basis between Federal use and non-Federal commercial licensed use, subject to flexible-use service rules. The critical constraint guiding DoD's examination of the band is that proposed sharing frameworks and their associated policy, standards, and technology implications must safeguard the primary mission of the military activities in the covered band. To this end, DoD seeks to establish a collaborative, transparent forum to exchange proprietary, sensitive, and classified information about defense and commercial spectrum operations -- the Partnering to Advance Trusted and Holistic Spectrum Solutions (PATHSS) Task Group. The target output from this body is the development of architectures and techniques (i.e., use cases) that will shape the future DoD sharing framework analysis and national regulatory environment. The proposed Task Group will include leaders and technical experts from DoD and across the breadth of the community of non-Federal stakeholders -- defense industrial base businesses, wireless technology suppliers and manufacturers, telecommunication service providers, local governments, academia, not-for-profit organizations, and other end-users whose business models may depend on spectrum access in the lower 3 GHz bands.*

3.6 Courses of Action

In June 2022, the PATHSS TG proposed spectrum sharing COAs to DoD personnel. The DoD-approved COAs drove the spectrum sharing approaches that were analyzed by the EMBRSS team. PATHSS TG collaboration continued to provide technical input and subject matter expertise throughout the process.

COAs were identified in accordance with the IIJA and subject to the DoD definition of spectrum sharing used for the EMBRSS feasibility assessment. Pursuant to DoD Instruction 4650.01, DoD defined spectrum sharing to include the following factors:

- Shared use of spectrum is without harmful degradation or interference in a manner that provides current and future users sufficient regulatory protection.
- Sharing does not result in loss of access to the spectrum.
- Use of spectrum that allows mutual use, without degradation or harmful interference, in a manner that provides current and future users sufficient regulatory protection, that does not result in loss of access to the spectrum.
- Sharing does not include vacating, compression, or repacking.[36]

[36] U.S. Congress, House Armed Services Committee, *Defense in a Digital Era: Artificial Intelligence, Information Technology, and Securing the Department of Defense, Before the*

This definition of spectrum sharing is consistent with the sharing principles defined in DoD policy.[37]

The PATHSS TG, through a consensus-driven, multi-stakeholder approach, developed the proposed spectrum sharing COAs to inform the EMBRSS team's evaluation. After the group brainstormed potential COAs, stakeholders were requested to: (1) evaluate technologies and concepts on the applicability and feasibility of each of the techniques with this band; (2) reach consensus on COAs (i.e., reduce the full list of identified COAs to those that hold promise to be viable options for spectrum sharing); (3) consolidate COAs that are similar; and (4) for agreed-on uses cases, ensure technical parameters are clearly defined including high-power and low-power variations, network architectures, intensity and criticality of use, receiver characteristics, and other parameters.

The final proposed COAs were:

- Active 5G Radio Access Network (RAN) (see **Figure 3.4**)
- Dynamic Spectrum Management System (DSMS) (see **Figure 3.5**)
- Radar Third Generation Partnership Project (3GPP) Digital Interference Cancellation (see **Figure 3.6**)

Based on a December 15, 2022, agreement between DoD and the Department of Commerce, additional COAs were examined across the Department, but not included as part of the PATHSS

House Armed Services Subcommittee on Cyber, Innovative Technologies, and Information Systems (statement of Honorable John B. Sherman, DoD CIO), 118th Cong. 1st sess., (March 9, 2023) at 11, https://armedservices.house.gov/sites/republicans.armedservices.house.gov/files/Sherman%20Testimony.pdf.

Mr. Sherman emphasized in his written testimony that "Within the 3100-3450 band, the DoD relies on hundreds of air, sea, and land-based radars for a wide range of missions. It would be untenable for DoD to outright vacate these systems from the parts of the spectrum in which they currently operate. To do so would take decades, cost hundreds of billions of dollars, and cause significant mission impacts to the Joint Force's warfighting readiness and capabilities."

[37] *DoD Instruction 4650.01*, "Policy and Procedures for Management and Use of the Electromagnetic Spectrum," (January 9, 2009), as amended, 3, https://www.esd.whs.mil/portals/54/documents/dd/issuances/dodi/465001p.pdf, "Sharing of spectrum shall be accomplished: (1) Without degradation to the DoD mission. (2) In a manner that provides current and future DoD users with sufficient regulatory protection. (3) With minimal risk that such sharing will result in loss of access to the spectrum necessary to perform the DoD mission."

TG process.[38] (*See classified annex*).

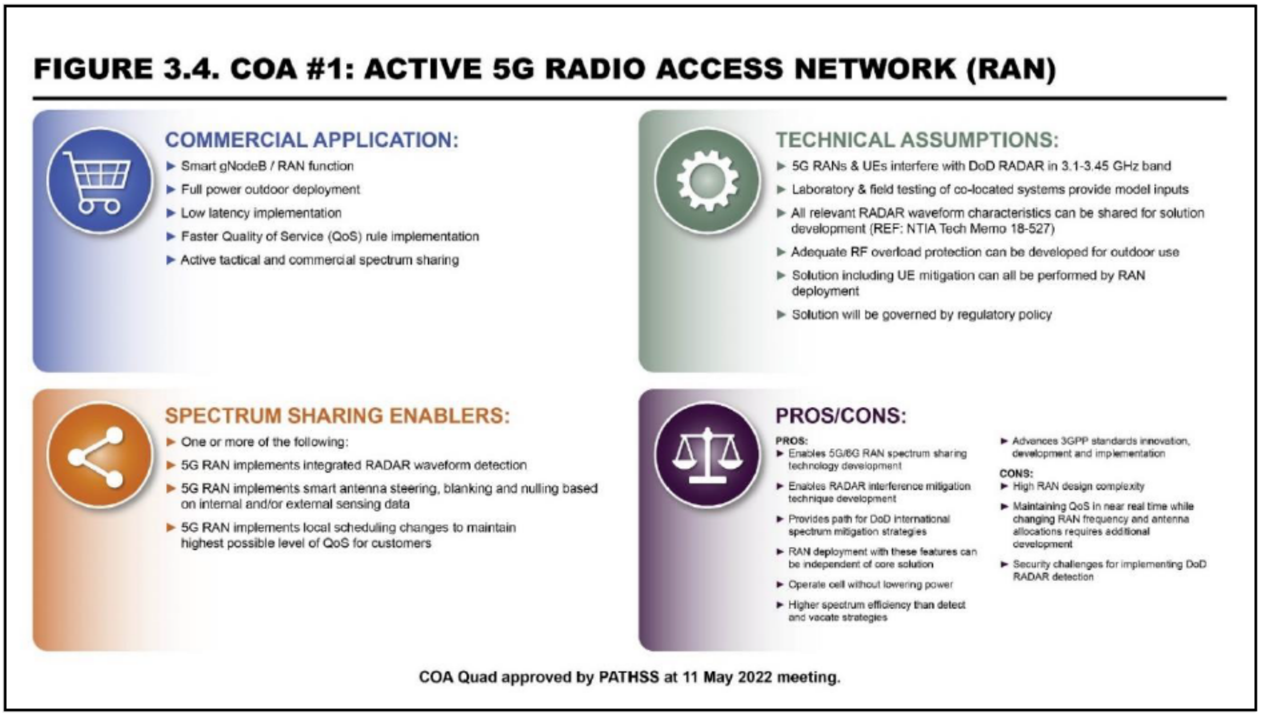
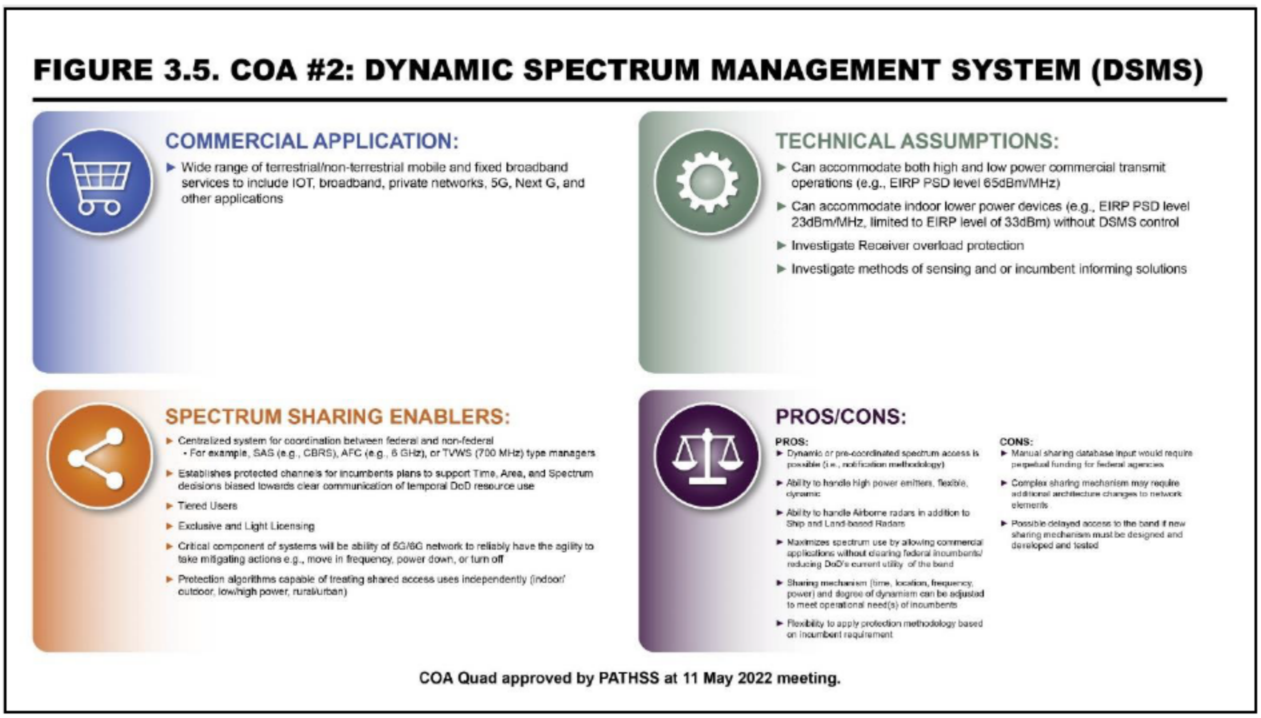


Figure 3.4: COA 1: Active 5G Radio Access Network (RAN)



[38] Department of Defense-Department of Commerce Agreement in Principle on IIJA Changes Re: Lower 3 GHz Spectrum (December 15, 2022). *See* **Appendix I**.

Figure 3.5: COA 2: Dynamic Spectrum Management System (DSMS)

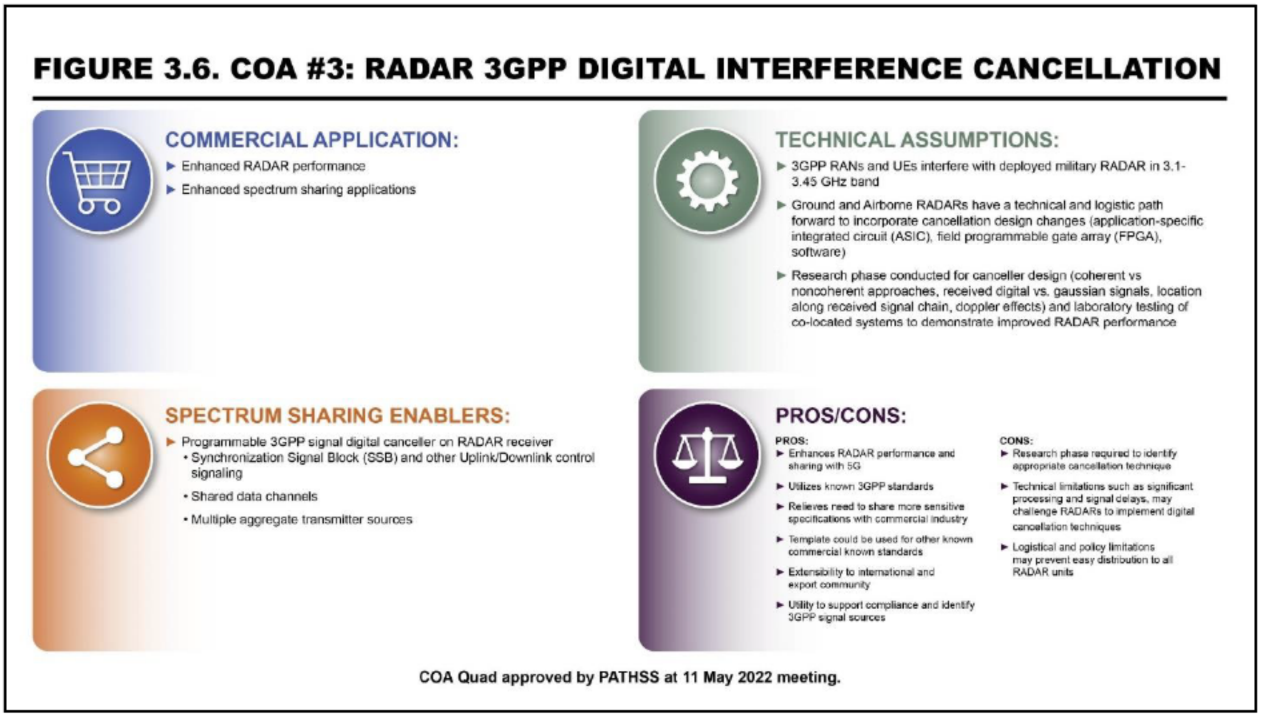


Figure 3.6: Radar Third Generation Partnership Project (3GPP) Digital Interference Cancellation (also referenced as Digital Cancellation of 5G)

3.7 Coordination within the Department of Defense

The DoD EMBRSS Ad Hoc Working Group met at least monthly since its inception in April 2022. The group included representatives from each of the Military Departments, from across DoD, and from other agencies with equities in 3100-3450 MHz, including DHS, NASA, and the U.S. Coast Guard. The group was charged with providing support to the EMBRSS technical team as part of their efforts to analyze each COA.

System-level, technical, and operational subject matter experts from across the Department were integral members of the working group and collaborated to shape the feasibility assessment's analytical outcomes. Due to time constraints, this authority facilitated coordination with subject matter experts across DoD Components. Under the auspices of the EMBRSS Ad Hoc Working Group, an Operational Requirements Verification (ORV) gathered data from operational units and system owners in the 3100-3450 MHz band. This covered systems, capabilities, and missions operating in the 3100-3450 MHz band and its adjacent ranges (2900-3100 MHz and 3450-3650 MHz).

3.8 Coordination across Government

Throughout the feasibility assessment, DoD conducted numerous engagements across the government to keep national policymakers informed and to create maximum transparency for this effort. As a member of the PATHSS TG and PATHSS-C, FCC provided valuable technical inputs to the PATHSS Working Group, facilitating discussions and furthering the report. DoD and NTIA shared co-chair responsibilities and met routinely to discuss technical parameters of the feasibility assessment.

Regarding funding oversight, OMB initiated a meeting with DoD on November 10, 2021, to discuss the $50 million from the Spectrum Relocation Fund (SRF) directed to DoD under Section 90008 of the IIJA and requested accounting data and a plan. The Department provided accounting information on January 12, 2022, with DoD providing the initial plan on January 20, 2022, and an updated plan on February 1, 2022. OMB then approved the SRF apportionment on January 24, 2022, and DoD received funds in March 2022. In July 2022, DoD briefed OMB with an update on the status of the feasibility assessment.

In addition, DoD briefed the Policy and Plans Steering Group membership on this effort on March 18, 2022, and November 17, 2022, and the status of the EMBRSS effort has been discussed via biweekly senior leadership meetings between NTIA and DoD.

CHAPTER 4: OPERATING ENVIRONMENT & ACTIVITIES IN THE BAND

4.1 Department of Defense's Operating Environment

The 3100-3450 MHz band is particularly critical to DoD operations and execution of the National Defense and Military Strategies. With the pacing challenge of the People's Republic of China, the acute threat posed by Russia, and threats to the U.S. homeland, the Department conducts critical training, testing and evaluation, and operations with its capabilities in this band. These activities range from operational functions that directly support the warfighter's readiness and ability to conduct operations to institutional functions that support the development and testing of critical capabilities. [redacted] The readiness of U.S. military forces hinges on their ability to conduct realistic training, the bulk of which takes place on ranges within the United States and its Possessions (US&P). Institutional functions include Federal test ranges and developmental contractor facilities that support developmental and operational testing as well as Federal training ranges, which combined help the Department to develop, field, and sustain operational capabilities to meet future threats.

This frequency band is also critical to Allied and Partner Nation systems for similar purposes. [redacted] FMS activities are sponsored and/or controlled by the U.S. Government and are part of the operating environment DoD agencies must work within. Allied services typically continue in operation after the U.S. service life ends, with a continuing need to maintain and update these products, and the commensurate need to maintain access to spectrum.

The Institute of Electrical and Electronic Engineers (IEEE) attributes typical use for the 3100-3450 MHz portion of the spectrum to search and track type radars. The primary transmitter types within this portion of the spectrum include radars and EW systems. DoD operates high-powered military radar systems on fixed, mobile, ground, shipborne, and airborne platforms throughout the band for air defense, missile and gunfire control, bomb scoring, battlefield weapon locations, air traffic warning and control, EW training, range safety, counter-UAS (C-UAS) operations, ballistic missile defense, and space domain awareness.

DoD operations span the entire US&P, with airborne systems operating nationwide, ground-based radars located at more than one hundred unique locations, and maritime platforms operating from more than twenty ports, as well as along the Atlantic, Pacific, and Gulf coasts.

Accessible radio frequencies (RFs) are crucial for warfighter training, testing, and operations. Ensuring access to the necessary electromagnetic spectrum (EMS) for DoD missions has proven more challenging as both government and commercial demand for spectrum continues to increase. Soldiers, Sailors, Airmen, Marines, and Guardians depend on the systems that operate within this spectrum to perform missions daily with capabilities that operate within the 3100-3450 MHz band.

The remainder of this chapter provides a summary of DoD activity in the 3100-3450 MHz band and the importance of the Department's activities. However, the presence of DoD activity should not be interpreted to imply that these activities are not compatible with, or could not be made interoperable with, shared use of this band.

4.2 Department of Defense Activities in the Mid-Band Spectrum

4.2.1 Department of Defense Activities Overview

DoD operations span the entirety of the US&P. [redacted] Each DoD Component has unique mission requirements associated with the primary domain in which they operate. The following paragraphs provide a summary of the key missions and systems for each Military Service and relevant Defense Agency:

U.S. Army: [redacted] The systems that operate in this band are primarily combat systems, but do support Homeland Defense missions, [redacted] The USA is required to conduct routine training with these systems to maintain readiness, which takes place at military training ranges and government and DoD contractor test facilities throughout the US&P.

U.S. Navy: The U.S. Navy (USN) uses the band extensively. [redacted] The USN is required to test and train on these systems, against threat representative emulators at military test and training ranges and facilities throughout the US&P.

U.S. Marine Corps: The U.S. Marine Corps (USMC) currently uses the band for both Air Surveillance and Counterfire missions. [redacted] The USMC is required to conduct routine training with these systems to maintain readiness, which takes place at military training ranges and facilities throughout the US&P.

U.S. Air Force: The U.S. Air Force (USAF) conducts various missions inside US&P including monitoring authorized traffic and unauthorized intrusions of U.S. airspace and humanitarian missions such as air traffic control following hurricane devastations. The USAF also uses this band for several operational capabilities, developmental prototype systems, EW, and test and training infrastructure. [redacted]

[redacted] The USAF is required to conduct routine training with these systems to maintain readiness, which takes place at military training ranges and facilities throughout the US&P. Additionally, the USAF normally conducts testing of weapons systems using capabilities that operate within this band at military test ranges and facilities throughout the US&P.

U.S. Space Force: [redacted]

Missile Defense Agency: The Missile Defense Agency (MDA) uses this band for tracking all classes of ballistic missiles and provides high resolution imagery for identifying small objects at long distances. [redacted]

[redacted]

[39] Brian G. Gladstone et al., *Cost, Schedule, and Operational Assessments for Vacating Critical Warfighting Assets Out of Their Operational Frequencies, Volume I: Main Document* (Alexandria, Virginia: Institute of Defense Analyses, June 2020).

[40] There are foreign partner variations of the AWACS platform, utilized by the North Atlantic Treaty Organization (NATO), France, Japan, and Saudi Arabia. These platforms routinely return to the United States to participate in military readiness and training scenarios (i.e., War Games) and for depot-level maintenance at defense contractor facilities.

[redacted]

[redacted]

Land-Based Radar Operations

The Army and USMC are the two primary Services that conduct operations supported by land-based radar systems. These operations are supported by systems that provide critical protection of the joint force through the detection and tracking of airborne and ground threats. Land-based radars provide surveillance and detection of airborne and ground targets at fixed locations or on mobile platforms. [redacted] This band is unique as it provides a compromise between the long-range detection and surveillance capabilities [redacted]

Mobile-Tracking Radar

Ground forces use mobile-tracking radars to detect and provide warning of incoming indirect fire (e.g., rocket, artillery, and mortar (RAM)) and to calculate its point of origin. That location data can be sent by a communications link to friendly forces, who can then fire on the enemy positions before they can reposition. Some examples of this use follow.

[redacted]

[redacted]

The Army also leverages [redacted] to detect, track, classify and locate direct and elevated threats which are fired at stationary or mobile forces. [redacted]

[redacted] Another variant of the system is as an Expeditionary Airport Surveillance Radar, which supports Air Traffic Control missions.

Electromagnetic Warfare

Ground forces leverage electromagnetic attack (EA) capabilities to defend against radio frequency (RF) initiated threats typically known as Radio Controlled Improvised Explosive Device (RCIED) using a [redacted] mounted or dismounted configurations. This system conducts defensive EAs to protect the service members. [redacted] Ground forces also use EA to degrade, disrupt, and deny adversary communications or may request support from air platforms to conduct EA.

Aircraft Survivability Assessments

DoD uses ground-based radars at [redacted] to provide high-quality, high-resolution ground-to-air dynamic radar measurements (i.e., radar cross section (RCS) signature measurements) for Program Managers and warfighters to make informed acquisition decisions and inform development of operational Tactics, Techniques and Procedures (TTPs) which enhance the effectiveness and survivability of USA, USAF and USN aviation platforms. These radars support the full range of science and technology (S&T), research, development, test, and evaluation (RDT&E) activities for military fixed wing, helicopter & UAS aircraft survivability assessments by characterizing aircraft radar signatures and dynamic contributors such as engines, rotors, propellers, and countermeasures. Radar signature measurement data directly influences [redacted]

[redacted]

[redacted]

Maritime Radar Operations

The Navy and Coast Guard are the two primary Services that conduct radar operations in and around all navigable waterways, including coastal waters throughout the US&P. They operate multi-function radar systems that perform defense, surveillance, detection, tracking and navigation. Inclement weather increases the dependency on these radar systems due to limited visibility of ships and other seaborne craft.

Radar-equipped platforms in the Navy provide for all-weather airborne early warning, airborne battle management and command and control functions for the Surface Action Group (SAG), Carrier Strike Group (CSG), and Joint Force Commander. Additional missions include surface surveillance coordination, air interdiction, offensive and defensive counter air control, close air support coordination, time critical strike coordination, search and rescue airborne coordination and communications relay. [redacted]

The Search and Rescue mission performed by the Navy and the Coast Guard requires both ship and airborne radar use to locate persons in distress along the East and West Coast of the United States, the Gulf of Mexico, the Great Lakes, and other waterways. The Navy and Coast Guard also participate in the drug interdiction mission, which may include both airborne and waterborne craft. This requires, once again, both ship and airborne radar use to detect, locate, track, and potentially engage suspect vessels.

Air Traffic Control

The Navy operates 11 aircraft carriers, seven Landing Helicopter Assault ships, and seven Landing Helicopter Dock ships with associated Air Traffic Control (ATC) systems to support their air operations mission. The systems operate in and around all navigable waterways, including coastal waters throughout the US&P. The systems are also required to operate while the ships are in shipyards during ship construction and repair (Newport News, Virginia; Norfolk, Virginia; Bath, Maine; Pascagoula, Mississippi; Portsmouth, New Hampshire; Bremerton, Washington; and San Diego, California) and in land-based test and training sites (St Inigoes, Maryland and Pensacola, Florida). Carrier Controlled Approach (CCA) radars installed on aircraft carriers and amphibious assault ships are part of the Navy's marshalling duties in its ATC system. The function of a CCA radar is to vector aircraft into final approach and consistently track them until touchdown on the flight deck. [redacted] Radars are being installed on CVNs and L-Class ships and they will perform the function of ATC for these ships. These radars are also used to maintain current locations, speeds, and altitudes of all aircraft in the vicinity to ensure safe flight operations.[41]

Backup Short-Range, Air-Search

The radar systems aboard naval vessels can serve as a backup short-range air-search radar system. In this mode, they can support [redacted], radar-driven threat engagements using munitions, long-range counter-fire and detect, surface-to-air and air-to-air data links and missile communication links, and long-range search functions, which are all critical to mission success and operations. The total bandwidth available within the band improves track and identification performance and electronic counter-countermeasures (ECCM).

Integrated Air & Missile Defense-Multi-Function Radar Systems

The Navy leverages Multi-Function Radars to execute BMD, AAW, and ship self-defense missions. The systems supporting these missions are utilized throughout navigable waterways within coastal waters of the US&P and in shipyards (Newport News, Virginia; Norfolk, Virginia; Bath, ME; Pascagoula, Mississippi; and Portsmouth, New Hampshire) during ship construction and repair. Additionally, there are four land-based test and training sites (Moorestown, New Jersey; Wallops Island, Virginia; Chesapeake Beach, Maryland; and Dahlgren, Virginia).

[redacted]

41 [redacted]

[redacted]

Airborne Operations

DoD operates high-power defense radar systems on fixed, mobile, and airborne platforms in the 3100-3450 MHz band to support air operations. These radar systems are used for critical airborne early warning and battle management and control, EW, air traffic surveillance and control, navigational station keeping for airlift operations, bird collision avoidance, weather observance, prediction, and avoidance, C-UAS operations, and space domain awareness.

Airborne Early Warning and Battle Management and Control

[redacted] The aircraft provides an accurate, real-time picture of the battlespace, providing for situational awareness of friendly, neutral, and hostile activity; all-altitude and all-weather surveillance and battle management and control of theater forces; and early warning of enemy actions during joint, allied, and coalition operations. The radar and computer subsystems [redacted] can gather and present broad and detailed battlefield information. This includes position and tracking information on enemy aircraft and ships and location and status of friendly aircraft and naval vessels. [redacted]

[redacted] provides the ability to find, fix, track and target airborne or maritime threats and to detect, locate and identify RF emitters. It has the ability to detect threats and control assets below and beyond the coverage of ground-based radar C2 systems and can exchange data with other C2 systems and shooters via datalinks.

[redacted]

Electromagnetic Warfare and Counter Unmanned Aerial Systems Operations

EW is a key enabler in DoD's ability to meet its national security commitments. It underpins the successful execution of global military operations by providing assured control of the electromagnetic spectrum (EMS) and establishing EMS superiority. EW is a force multiplier for a range of military operations: maximizing the lethality of precision-strike weapons; assuring mission command; and increasing mobility by protecting complex battle networks, weapon systems, and forces. Within the US&P, U.S. military forces primarily conduct EW testing, training, and large-force exercises (LFEs) on DoD test and training ranges and facilities within military operating areas and airspace. [redacted]

[redacted] Currently, EA is primarily focused on adversary radars in band. The USAF's EA capabilities used to support air and [redacted] operations include: [redacted]; Defensive EA and chaff systems on its tactical aviation platforms; [redacted] Those purpose-built EA capabilities differ from the majority of USAF tactical aircraft (fighters, bombers, special operations, rotaries) which are equipped with defensive self-protection EA systems designed to counter adversary radar-aided, guided surface-to-air missile (SAM) systems, anti-aircraft artillery (AAA), and airborne interceptors (AIs). [redacted]

[redacted]

The USN's EA capabilities that support airborne and [redacted] operations include: [redacted]; Defensive EA and chaff systems on its tactical aviation [redacted] As with the USAF, the USN's tactical aircraft are also equipped with defensive self-protection EA systems that are designed to counter adversary radar-aided, guided SAM systems, AAA, and AIs.

The USMC's EW capabilities that support airborne operations include airborne platforms that provide offensive EA and electromagnetic sense (ES) (Intrepid Tiger II Pod). Comparable to the USAF and the USN, USMC tactical aircraft can also be equipped with defensive self-protection EA systems that are designed to counter adversary radar-aided and guided SAM systems, AAA, and AIs.

Air Traffic Surveillance and Control

[redacted] These systems are designed to be deployed on an operational basis at unspecified locations worldwide and are currently being operated at airbases and training and test ranges throughout the US&P.

Navigational Station Keeping for Airlift Operations

[redacted] This information is critical to maintain safe aircraft separation and mission execution during IMC. These aircraft formations are a key component to the menu of available options when it comes to force projection capabilities available to the nation to deliver combat forces. [redacted]

In a letter to the FCC on September 8, 2020, NTIA stated "The U.S. Air Force plans to replace the system with one that operates in another band in order to improve 5G spectrum availability and operational effectiveness of the necessary SKE mission. This process may take up to a decade before all aircraft are retrofitted with the new equipment. To ensure readiness until the system is replaced, the Air Force will only use the lower 40 megahertz of the band (3450-3490 MHz) in two Cooperative Planning Areas (CPAs), providing immediate access to the upper 60-megahertz segment (3490-3550 MHz) with the possibility of the entire 100 megahertz becoming available with successful coordination across two CPAs where high tempo operations occur." The letter noted both that the SKE system has compressed operations in the AMBIT band and that the system replacement may take a decade.[42]

Bird Collision Avoidance

The [redacted] are used to track bird migration patterns, provide warning to aircrew of hazardous flight conditions caused by bird activity, and decrease potential bird strikes to aircraft. These systems are deployed at airbases and test and training ranges throughout the US&P.

[42] U.S. Department of Commerce, National Telecommunications and Information Administration, *Amendment of the Commission's Rules with Regard to Facilitating Shared Use in the 3100-3550 MHz Band (WT Docket No. 19-348)*, by Mr. Charles Cooper, Associate Administrator, NTIA to Mr. Ronald T Repasi, Acting Chief, Office of Engineering and Technology, FCC and Donald Stockdale Ph.D., Chief, Wireless Telecommunications Bureau, FCC (Washington, D.C.: September 8, 2020), https://www.ntia.doc.gov/files/ntia/publications/ntia-osm_letter_to_fcc-oetwtb_re_3450-3550_mhz_fnprm_9-8-20.pdf.

Space Domain Awareness

[redacted]

[redacted]

[redacted]

[redacted] training operations include Federal test ranges and developmental contractor facilities for research and development (R&D) performance verification and training centers to validate total combat system designs and conduct engineering development, testing, and evaluation. These sites enable design and fabrication of products, monitor production, certify [redacted] integrate and test combat systems equipment and computer programs, and evaluate operational suitability. Several of these test sites make up the DoD Major Range and Test Facility Base (MRTFB) ranges. They are a multi-domain, full-spectrum, land, water, and airspace dedicated to supporting testing and evaluation (T&E), experimentation, demonstration, and training activities across the Services, Joint Force, and coalition partners. The MRTFB ranges support rapid response and traditional acquisition activities associated with performance, effectiveness, and suitability evaluations in realistic threat environments. The MRTFB ranges [redacted] be preserved as a national asset to provide the capabilities needed to support DoD acquisition. They use numerous instrumentation systems and range support capabilities that operate at many different frequencies.

DoD contractor ranges also play a critical role in R&D, developmental testing, production testing, and system sustainment activities. These activities are generally conducted under U.S. USG contract both for DoD and Allied system deployments. T&E is conducted at DoD contractor ranges as part of the production process and to verify integration of upgrades. Contractor ranges also support essential sustainment operations with the development and verification of next generation capabilities for existing and future radar systems as well as product repairs during a system's entire lifecycle.

[redacted]

- [redacted]
- [redacted]

Test Measurement Capabilities

The Test Measurement Capabilities category includes capabilities the DoD has to test the performance or an attribute of a system in acquisition. Test measurement capabilities reside at both Federal and developmental contractor facility test ranges or facilities and are used to measure a multitude of different aspects of weapon systems. One example is to test the detectability of an aircraft system by a radar or to characterize the Radar Cross Sections (RCS) of different airborne and ground-based targets such as aircraft, missiles, or tanks (see Aircraft Survivability Assessment section above for more details). These same ranges also test different radars to verify operation or for training purposes. Realistic Threat Representation systems encompass test range systems that are used to replicate threat systems warfighters would encounter in combat. Adversarial nations have deployed radar systems in this frequency band to acquire and track both U.S. and allied aircraft. Therefore, test ranges use threat representative systems to emulate adversarial capabilities to assess the performance of U.S. aircraft to defend against these threat capabilities. Experience has shown that adversaries are quick to exploit areas of vulnerability to operational capabilities, including in the RF spectrum [redacted]

Another example of Test Measurement Capabilities is Electromagnetic Environmental Effects (E3) testing. E3 is defined as the impact of the electromagnetic environment (EME) on the operational capability of military forces, equipment, systems, and platforms. E3 encompasses the EM effects addressed by the disciplines of EM compatibility, electromagnetic interference (EMI), EM vulnerability, electromagnetic pulse (EMP), EM protection, electrostatic discharge (ESD), and hazards of EM radiation to personnel, ordnance, and fuels or volatile materials. E3 includes the EM effects generated by all EME contributors including RF systems, ultra-wideband devices, high-power microwave systems, lightning, and precipitation static. E3 control includes the mitigating effects of the EME, starting early in the acquisition process so execution of an operational mission is not prohibited, capabilities are not significantly reduced, or system vulnerability is not increased. This type of testing is conducted at the NAWCAD and Naval Air Warfare Center Weapons Division (NAWCWD), White Sands Missile Range, NM and Naval Surface Warfare Center, Dahlgren, VA facilities with multiple RF systems. The purpose of E3 testing is to achieve system compatibility and spectrum supportability in the operational EME.

Shipboard Electronic Systems Evaluation Facilities (SESEF) are test measurement capabilities that provide EM systems test and evaluation services to afloat and ashore combat commands. SESEF capabilities include quick-look operability tests and system performance testing. Emphasis is placed on providing real-time EW and RF signal analysis while minimizing test time. SESEF locations in Virginia, Florida, Washington, California, and Hawaii provide real-time testing for Navy ships underway in an operational environment.

SESEF operations are conducted 24 hours a day and 7 days a week. These facilities are always on call and responsive to Fleet OPTEMPO (operational tempo) and demand. The primary purpose and intended use of the capability is shipboard testing, analysis, troubleshooting, and calibration of electromagnetic (EM) systems, including shipboard EA/ES/direction finding (DF) systems. SESEF accomplishes this mission with real time comparative EW and RF signal analysis consistent with an operational environment. Testing is conducted while ships are underway and in pre-deployment status. SESEF ranges fall under the Naval Sea Systems Command (NAVSEA).

Realistic Threat Representations

For realistic threat representations, open air ranges allow assessment of kinetic (countermeasures) and non-kinetic (EA) warfighting TTPs, mission planning, and enhancements to aircraft survivability and platform vulnerabilities against adversarial radar systems, threats, and countermeasures. The Department requires both over-land and over-water EW and EA T&E capabilities. [redacted] This complex laydown of threats supports operationally realistic testing of EW systems of leading-edge platforms [redacted]

[redacted] These systems provide a threat representative laydown necessary to prove the EW and EA key performance parameters for the [redacted] The Atlantic Test Range employs most of the eastern corridor to provide key EW and EA testing for the [redacted]. Both NAWCAD and NAWCWD conduct rapid response activities to meet global operational demands and other urgent needs of the DoD.

The EW and EA capabilities of these test ranges utilize several current systems as well as new systems that are just now in the planning and development stages. New EW/EA systems will have similar RF operating characteristic of the existing systems.

DoD's Tri-Service Realistic Threat Representations (Test Resource Management Center (TRMC)) is developing several realistic threat representation systems which are intended to address tri-service EW requirements and transition to Service Major Range and Test Facility Base sites. These systems include next generation, high-power RF threat emitters [redacted]

In conjunction with the Services and Director, Operational Test & Evaluation (DOT&E), the TRMC developed a Joint EW T&E Strategy (JETS) aimed at developing and implementing advanced EW capabilities, a portion of which supports more realistic threat representations. Capabilities currently in development that require access to spectrum in this range include:

- Developmental RF threat systems with multiple high-power Open-Air Range radars
- Expansion of a more complex RF battlespace that spans multiple test ranges
- Increased in force-on-force level missions

Below are several ranges that conduct operations in this band, with a description of the facility and its principal use.

White Sands Missile Range, New Mexico (Army)

WSMR, an Army-owned range located in south-central New Mexico, is the nation's premier location for conducting weapons system test and evaluation. [redacted]

WSMR is DoD's largest fully-instrumented open air range, with 2.2 million acres of land and more than 10,000 miles of restricted airspace (expandable to more than 11,000 miles). The NRTF test capability is centrally located on WSMR and covers an area of 1,576 acres. The remote WSMR location [redacted] provides the necessary security and quiet EMS environment to accomplish NRTF's mission.

Nevada Test and Training Range, Nevada (Air Force)

The Nevada Test and Training Range (NTTR), located in southern Nevada, is a USAF-owned range that supports DoD advanced composite force training, tactics development, and electronic combat testing as well as DoD and Department of Energy testing, research, and development. NTTR hosts numerous Red Flag and USAF Weapons School exercises each year, as well as various test and tactics development missions. NTTR is the largest contiguous air and ground space available for peacetime military operations in the free world, occupying 2.9 million acres of land, 5,000 square miles of restricted airspace, and another 7,000 square miles of airspace shared with civilian aircraft.

Naval Air Warfare Center Weapons Division, China Lake Land Range and Point Mugu Sea Range, California (Navy)

NAWCWD China Lake, located in the Western Mojave Desert region of California, supports the USN's RDT&E of cutting-edge weapons systems in areas such as battlespace integration, airborne EA, aircraft survivability, counter-improvised explosive devices, directed energy, robotics, and energetics. China Lake is the Navy's largest single landholding, representing 85 percent of the Navy's land for RDT&E use and 38 percent of the Navy's landholdings worldwide. In total, its two ranges and main site cover more than 1.1 million acres. Its 19,600 square miles of restricted and controlled airspace make up 12 percent of California's total airspace and provide an unprecedented venue for integrated testing and training. Additionally the NAWCWD Point Mugu Sea Range encompasses 36,000 square miles of sea space off the coast of Point Mugu, California. The Pt Mugu Sea Range is used for surface-to-air, air-to-air and air-to-surface weapons testing, directed energy test and evaluation, ship self defense testing against subsonic and supersonic targets and is a key venue for testing EW systems against integrated air and missile defense systems, to include open air threat emulators, in a maritime environment.

Yuma Proving Ground, Arizona (Army)

Yuma Proving Ground, located in the southwest corner of Arizona, is a multi-purpose, Army-owned test complex for artillery, manned and unmanned aviation systems, armor, tactical vehicle, electronic countermeasure, C-UAS (Groups I-III), and air delivery testing. Due to its rugged terrain and extreme heat, Yuma also serves as the Army's desert environment test and evaluation center to challenge equipment in demanding real-world conditions. Yuma Test Center is one of DoD's largest landholders, with facilities and ranges covering more than 1,300 square miles of land and 2,000 square miles of restricted airspace.

Eglin Air Force Base, Florida (Air Force)

Eglin AFB, located in the northwest corner of Florida, is the DoD's second largest test and training complex and the test and evaluation center for USAF air-delivered weapons, navigation and guidance systems, command and control systems, and USAF Special Operations Command systems. The Eglin Gulf Test Range provides approximately 120,000 square miles of overwater airspace, covering the eastern third of the Gulf of Mexico from the Florida panhandle to the Florida Keys. The land range covers 724 square miles and contains 70 specific test and training areas, including an approved depleted uranium test range and the only qualified air-to-ground supersonic range east of the Mississippi River.

Naval Air Warfare Center Weapons Division, Patuxent River, Maryland (Navy)

NAS Patuxent River, located in southern Maryland at the confluence of the Chesapeake Bay and the Patuxent River, is the Navy's principal RDT&E, engineering, and fleet support activity for manned and unmanned aircraft, engines, avionics, aircraft support systems and ship/shore/air operations. The Atlantic Test Ranges are instrumented to provide full-service support for cradle-to-grave test and training for aircraft, aircrew, and subsystems. The center manages more than 2,700 square miles of restricted airspace including targets and airspace over the mid-Atlantic seaboard. Scheduling offshore warning areas, where support is typically provided, expands that area to more than 50,000 square miles.

Navy Homeport Locations

Aside from the six test ranges that require Periodic Use Areas (PUAs) to retain critical test capabilities, the AMBIT technical analysis identified the requirement to protect SESEF operations located near Navy Homeport locations. SESEF provides EM systems test and evaluation services to afloat and ashore combat commands. SESEF capabilities include quick-look operability tests and system performance testing. Emphasis is placed on providing real-time EW and RF signal analysis while minimizing test time. SESEF locations in Norfolk, Virginia; Mayport, Florida; Ediz Hook, Washington; San Diego, California; and Waianae, Hawaii provide real-time testing for Navy ships underway in an operational environment.

Training

Every day of the year, our joint forces (including both active-duty and reserve components) train in all domains, both on and off federal lands. During training, units gain the proficiency to operate their weapon systems with the goal of certification to conduct successful combat operations. As the Department focuses its attention on the near-peer fight, the ability to access and maneuver within the EMS becomes critical. Specifically, the training community requires spectrum access to operate spectrum-dependent systems, EA, enable Electromagnetic Support, and replicate a contested EMS to train Electromagnetic Protection. Historically, DoD has conducted training on ranges using live platforms to make training. Training realism came from the employment of real platforms, weapons, and actual combat tactics. [redacted]

4.3 Other Federal Operations in the Band

4.3.1 National Aeronautics and Space Administration

Under the primary radionavigation allocation, NASA operates the City Environment for Range Testing of Autonomous integrated Navigation (CERTAIN) at its Langley Research Center in coordination with Langley Air Force Base (AFB). CERTAIN Flight Test Range is a group of 8 ranges for UAS/UAV research. CERTAIN allows free flight of compliant UAS/UAV vehicles which must be <25lbs, at altitudes up to 400' (AGL) and up to 75 knots. CERTAIN supports NASA's mission to conduct research, testing, and development to advance aeronautics.

Under the secondary Earth exploration satellite service allocation in the 3100-3300 MHz band, NASA partnered with the Indian Space Research Organization (ISRO) to study hazards and global environmental change. The NASA-ISRO Synthetic Aperture Radar (SAR) (NISAR) Mission will measure Earth's changing ecosystems, dynamic surfaces, and ice masses providing information about biomass, natural hazards, sea level rise, and groundwater, and will support a host of other applications. NISAR will observe Earth's land and ice-covered surfaces globally with 12-day regularity on ascending and descending passes, sampling Earth on average every 6 days for a baseline 3-year mission. Currently in development, NISAR is slated to launch in 2024.

4.3.2 Department of Homeland Security

The Department of Homeland Security (DHS) utilizes this radionavigation band for conducting aerial surveillance operations in every boarding domestic state and coastal areas of U.S possessions. The United States Secret Service, Customs and Border Protection, and Science and Technology (S&T) components of DHS conduct air surveillance operations for the detection, identification, and tracking of aerial targets potentially supporting adversarial or illicit operations such as drug distribution and human smuggling activities. Additionally, DHS components also utilize radar systems in this radio-frequency band that employ counter-fire and targeting capabilities to identify points of origin of low flying objects impacting law enforcement operations.

4.4 Summary

The 3100-3450 MHz band is essential to DoD for training, testing and evaluation, and operations, including critical homeland defense missions. Specifically, access to this band is vital for a variety of fixed, mobile, ground, shipborne and airborne radar systems that support numerous tests, training, and operational missions conducted throughout the US&P. These high-power radar systems directly enable ballistic missile defense, airborne early warning and control, electronic surveillance and reconnaissance, air traffic control and bird collision avoidance, weather observation, forecasting and avoidance, navigational station keeping, counterfire mission support, C-UAS support, and EW. Additionally, DoD conducts test operations MRTFBs across the US&P, providing invaluable test measurement capabilities and realistic threat representation to validate total combat system designs and conduct engineering development, testing, and evaluation providing for the effective and responsive acquisition of essential capabilities. Finally, this band is crucial to the DoD's ability to conduct live, realistic training, spanning all domains, to enable the military readiness of the Joint Force.

CHAPTER 5: CRITICAL ASSUMPTIONS

The EMBRSS feasibility assessment was guided by the critical assumptions identified below. Additional detailed assumptions about specific parts of the analysis are included in Chapters 6 and 7.

5.1 Foundational Assumptions

- Accessible radio RFs are crucial for warfighter system development, testing, training, and operations.

- Spectrum, free from harmful interference, must be available to ensure that: (1) Systems operate as required (developmental and operational testing), (2) Training can be conducted with baseline conditions, in emulated, contested environments (training) that are representative of real-world threats and (3) the ability to support and implement the National Security Strategy is not impacted as a result of degraded system performance and reduced operator proficiency (operations).

- Reallocation of the 3100-3450 MHz band based on sharing must ensure access to sufficient EMS for homeland defense and military systems and operations critical to national security objectives.

- Spectrum sharing frameworks must ensure continued DoD access to the 3100-3450 MHz band, including accommodation of frequency assignments for future systems. The Federal regulators and managers will need to consider the Federal and non-Federal equities and priorities in a proceeding and continue to coordinate any shared use throughout operations in the band.

- The priority of the feasibility assessment is to provide unbiased analysis so subsequent decisions about frequency use will not impact the primary mission of DoD operations in the band: "The Secretary of Commerce may identify frequencies under subparagraph (A)(ii) only if the Secretary of Defense has determined that sharing those frequencies with non-Federal users would not impact the primary mission of military spectrum users in the covered band. In making that determination, Congress directed DoD to assess 'activities with respect to systems, or other planning activities to improve efficiency and effectiveness of the spectrum use [for DoD systems]."[43]

- Sharing frameworks will be assessed with respect to their impact on the mission of military spectrum users in the 3100-3450 MHz band. Scenarios likely to result in degradation and/or loss of critical primary mission capabilities cannot be considered feasible for spectrum sharing.

[43] Infrastructure Investment and Jobs Act, P.L. 117-58, § 90008(b)(2)(B) (2021).

[redacted]

- Different spectrum sharing solutions, in combination, may be required for the protection of all DoD systems operating in the 3100-3450 MHz. As part of the PATHSS process, DoD has adopted a definition of sharing that does not result in a loss of access to the spectrum and that does not include vacating, compression, or repacking.

- Spectrum sharing solutions must include mechanisms for reporting, identifying the source(s) of, adjudicating, and mitigating harmful interference to DoD systems in a timely manner.[44]

- Moreover, the band is internationally harmonized, having been identified by dozens of countries for 5G use. This enables interoperability and international roaming, allowing citizens to use the same device in different countries. Harmonization of spectrum boosts economies of scale, making devices and services more affordable.[45] Thus, the Lower 3 GHz band is a critical part of the global 5G effort and equipment is already available that could be deployed by providers seeking to use this band.

5.2 Technical Assumptions

5.2.1 General Technical Assumptions

- The three spectrum sharing Courses of Action (COAs) developed by the the PATHSS TG (i.e., Active 5G Radio Access Network (RAN); Dynamic Spectrum Management System (DSMS), Digital Cancellation of 5G, and/or interference excision) represent industry stakeholder recommendations for spectrum sharing solutions in the 3100-3450 MHz band, subject to the reports definition of spectrum sharing.

- Spectrum sharing framework COAs are technically feasible and will ensure DoD systems achieve comparable capability.

- The output generated from the EMBRSS analysis is founded upon authoritative data and the range of operating conditions essential to meet assigned military missions and supporting activities.

- Technical inputs include a combination of real-world measured data; inputs from commercial industry, DoD, and documents from international and domestic regulatory bodies; and deployment information available from prior domestic spectrum sharing

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[44] "Terms and Definitions," 47 C.F.R. § 2.1(c) (2020), https://www.ecfr.gov/current/title-47/chapter-I/subchapter-A/part-2/subpart-A/section-2.1.
"Harmful Interference. Interference which endangers the functioning of a radionavigation service or of other safety services or seriously degrades, obstructs, or repeatedly interrupts a radiocommunication service operating in accordance with [the ITU] Radio Regulations."

[45] ITU News, *"WRS-22: Global harmonization paves road to WRC-23"* (January 25, 2023), https://www.itu.int/hub/2023/01/global-spectrum-harmonization-wrc-process.

[redacted]

initiatives. These data sources provide an initial basis (in some cases low fidelity) for modeling commercial 5G and DoD systems.

- The technical analysis utilized authoritative data regarding DoD systems and the range of operating conditions essential to meet their assigned military missions and supporting activities; some DoD data is classified at the Secret, Top Secret, and Special Access Program (SAP) levels.

5.2.2 DoD System Technical Assumptions

- Interference Protection Criteria (IPC) are used as a basis to protect DoD system operations from interference. Systems are designed assuming these IPCs are in place.

- The IPC thresholds can serve as an imperfect but useful proxy for assessing impact to DoD systems' Key Performance Parameters for their primary missions.[46]

- DoD radar systems are deployed with a standoff distance from foliage and structures to maximize their performance.

- DoD mission impacts from future commercial wireless systems operating in the 3100-3450 MHz band can be assessed by comparing the predicted aggregate interference power at the radar receiver to the radar noise floor.

5.2.3 Commercial Wireless 5G Technical Assumptions

- This feasibility assessment only looks at 5G as the commercial wireless system that would be entering the band.

- Commercial deployments will be consistent with what industry has reported in the Commerce Spectrum Management Advisory Committee (CSMAC) 2012 relative to commercial wireless deployments and will include both macro and micro cell radio systems.

- Commercial deployments will be Time Division Duplex.

- Deployments will consist of high-, medium-, and low-power scenarios.

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[46] U.S. Department of Commerce, National Telecommunications and Information Administration, *Interference Protection Criteria* (October 2005), NTIA Report 05-432, https://www.ntia.doc.gov/files/ntia/publications/ipc_phase_1_report.pdf.

Interference Protection Criteria (IPC): A relative or absolute interfering signal level defined at the receiver input, under specified conditions, such that the allowable performance degradation is not exceeded. This is usually defined as an absolute interference power level I, interference-to-noise power ratio I/N, or carrier-to-interfering signal power ratio C/I.

- Interference aggregates from multiple transmission sources.

- Macro-cell deployments use Advanced Antenna System.

- Interference to DoD systems from 5G uplink (UL) emissions is small in comparison to downlink emissions.

- Interference mitigation solutions modeled within the 5G network for the Active 5G RAN COA will at a minimum achieve the interference reduction assumed in this report.[47]

- Additional detailed technical assumptions are included in Chapter 6, Analysis Approach.

- Internet of Things (IoT) was considered separately.

5.3 Operational Assumptions

5.3.1 Department of Defense Operational Assumptions

- In the aggregate, and in some cases individually, the incumbent Federal operations geographically span the entire United States and its Possessions (US&P) but not necessarily operating at the same time.

- The Department of Defense (DoD or Department) must be able to operate over the entire geographic area of their associated military installations to include shipyards, DoD Test and Training Ranges, Contractor facilities, littoral/coastal water areas of current and future authorized operating radius. Emitters could be located along the installation boundary; however, for modeling purposes, ground mobile emitters have in some cases been modeled outside of installation boundaries but consistent with their intended mission applications.

- To conduct the development, testing, and training required in preparation for operating their systems globally, DoD must maintain access to the entire 3100 to 3450 MHz spectrum band. [redacted]

- Interference mitigation techniques must not restrict DoD systems from meeting mission requirements.

- Advanced notification of DoD use within the band generally is expected but may not be feasible in every instance for many systems and missions, but may be an option for research, development, test, and evaluation (RDT&E) and training activities. DoD retains priority access to the spectrum as needed to meet mission requirements.

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[47] Interference Mitigation: The act of reducing the interfering signal level at the receiver input.

- DoD will provide the final determination on operational security and cyber security concerns associated with spectrum sharing solutions.

5.3.2 Commercial Wireless 5G Operational Assumptions

- 5G networks will span the entire US&P

- Deployment characteristics will reflect different population densities (Urban, Suburban, Rural) and 5G business cases that involve high-, medium-, and low-power scenarios and differing macro and micro cell radio types and antenna heights. Preference is not given to any particular population density, power, radio type or antenna height scenario.

- The performance achieved by 5G when implementing the spectrum sharing Courses of Action (COAs) will contribute towards achieving national wireless broadband priorities while maintaining DoD's ability to conduct National Security related operations.

5.4 Cost and Schedule Assumptions

- As a threshold consideration, cost estimates for all systems and scenarios are preliminary and representative—not conclusive.

- As provided by 47 USC 923(g), DoD will be provided sufficient time to prepare detailed cost estimates for reimbursable sharing costs as part of transition plans prepared in advance of an auction. Such cost estimates will provide a more precise level of detail that will, in turn, inform the reserve price for future auction.

- DoD will be provided sufficient time to implement changes required to support spectrum sharing solutions, including, but not limited to; modifications to Tactics, Techniques, and Procedures (TTPs) and Concept of Operations (CONOPs), acquisition of materiel solutions, and sufficient testing of solutions prior to deployment.

- Cost implications in the report are addressed holistically regarding overall operational impact to DoD, including mission readiness and life-cycle factors such as the time required to remove, capabilities from deployment to upgrade and retrofit with identified sharing solutions (e.g., dry docking ships, etc.).

- DoD plans to rely on Spectrum Relocation Fund (SRF) sources to cover anticipated sharing costs.

- Cost and schedule estimates will vary by spectrum sharing Course of Action (COA), with some costs likely higher for industry (i.e., Active 5G Radio Access Network (RAN)) and others expected to place a higher cost and schedule burden on the Department (i.e., Radar Third Generation Partnership Project (3GPP) (also referenced as Digital Cancelation of 5G)). The scope of this report is focused on cost and schedule implications to the Department and its components.

- Cost considerations are bounded by the requirements of current statutes governing SRF implementation, including "comparable capability" and the limitations on the long-term sustainment costs for advanced forms of sharing (i.e., long term operations of coordination portals). Any deviation from these factors would be contingent on future legislative changes.

- Comparable capability is limited to "incidental increases in functionality" for DoD and other Federal users under SRF statutory provisions. Specifically, 47 U.S.C. 923(g)(B) states comparable capability of systems: "(i) may be achieved by relocating a Federal Government station to a new frequency assignment, by relocating a Federal Government station to a different geographic location, by modifying Federal Government equipment to mitigate interference or use less spectrum, in terms of bandwidth, geography, or time, and thereby permitting spectrum sharing (including sharing among relocated Federal entities and incumbents to make spectrum available for non-Federal use) or relocation, or by utilizing an alternative technology; and (ii) includes the acquisition of state-of-the-art replacement systems intended to meet comparable operational scope, which may include incidental increases in functionality."

- Modification of assignments of this band will not occur earlier than May 31, 2025 under Section 90008(b)(5) and an auction will not occur earlier than November 30, 2024 under Section 90008(b)(3).

CHAPTER 6: ANALYSIS APPROACH OVERVIEW

6.1 Introduction

The EMBRSS feasibility assessment evaluated multiple courses of action (COAs) regarding the feasibility of spectrum sharing in the 3100-3450 MHz band.

This chapter is limited to baseline, COA 1, and COA 2. COA 3 was not modeled due to limitations based on the maturity of technology and lack of available data.

6.2 Approach

To conduct this feasibility assessment, the DoD:

- Embraced rigorous, scientific, and evidenced-based analysis, informed and validated by industry and government, including NTIA.[48]

- Collaborated with government, industry, and academia stakeholder groups to collect the information required to assess the feasibility of spectrum sharing in the 3100-3450 MHz band.
    - Estimated deployment, configuration, and technical characteristics for current USG and future 5G operations in the 3100-3450 MHz band.
    - Determined COAs to be used when assessing spectrum-sharing improvements.

- Identified and developed models to represent all the critical components in an EMBRSS spectrum-sharing assessment (detailed below).

- Using the models and other inputs, assessed the feasibility and opportunities for 3100-3450 MHz spectrum sharing.

6.3 Engineering Model Concepts Overview

The EMBRSS analysis evaluates opportunities for spectrum-sharing between a commercial 5G network and an incumbent USG system by modeling the aggregate interference from the 5G network into the USG system. The key components of this interaction, include the locations and properties of a 5G Network and the USG system, the physical mediums that the radio signal travels through, and the ability of the USG systems to meet their mission requirements while sharing spectrum with the 5G network. **Figure 6.1** shows how a spectrum-sharing scenario is modeled for the purpose of this analysis. In this figure, a 5G network was placed in a geographic

[48] President Joseph R. Biden, Jr., *Memorandum for the Heads of Executive Departments and Agencies, Subject: Memorandum on Restoring Trust in Government Through Scientific Integrity and Evidence-Based Policymaking,* Washington, DC, January 27, 2021, https://www.whitehouse.gov/briefing-room/presidential-actions/2021/01/27/memorandum-on-restoring-trust-in-government-through-scientific-integrity-and-evidence-based-policymaking/

area around the incumbent USG system. The signals from each 5G transmitter broadcast through or around the surrounding environment, including to the USG receiver.

FIGURE 6.1: DEPICTION OF A STANDARD COMPATIBILITY SCENARIO WITH A 5G NETWORK, A USG SYSTEM, TERRAIN, AND RADIO LINKS.

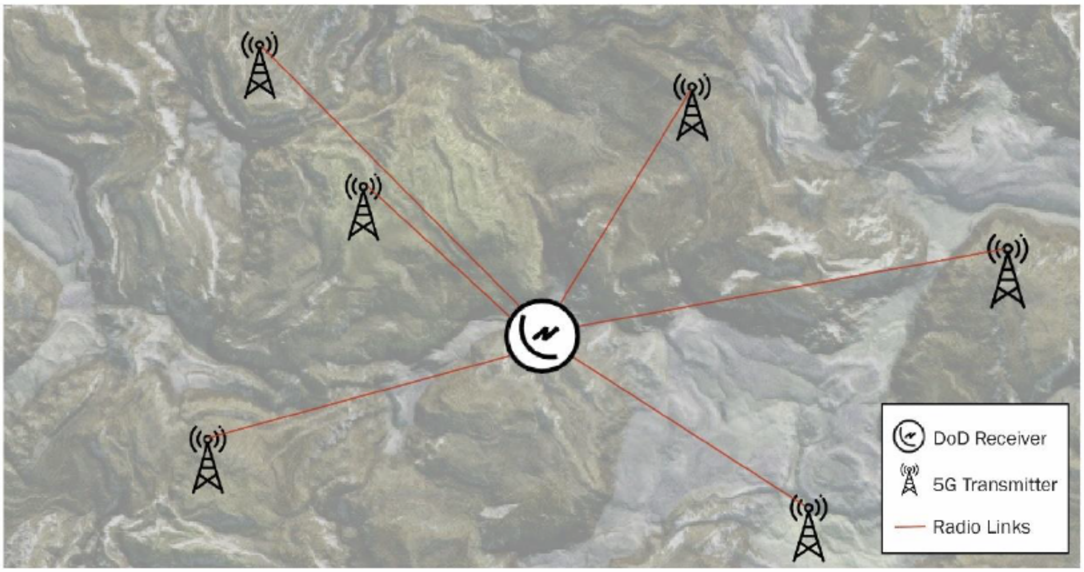

Figure 6.1: Depiction of a Standard Compatibility Scenario with a 5G Network, a DoD System, Terrain, and Radio Links

A link budget equation is used to determine the interference power at the USG receiver from each 5G transmitter. The sum of the interference power received from the network of 5G transmitters, is known as aggregate interference and is used to determine whether the USG system and 5G network can share the spectrum. If the USG receiver IPC is exceeded, 5G network transmitters were turned-off in the model, until Interference Protection Criteria (IPC) was met. (See **Section 6.9**.)

RFarchitect, a radio frequency modeling tool, served as the basis for the EMBRSS analyses using the engineering model described above. RFarchitect is able to model both the USG receivers and the base station transmitting radios at their respective geographical locations. Using established models such as TIREM (see **Section 6.7.1**), along with the ability to make use of 3D antenna patterns, the system can calculate link budgets, analyze aggregate effects, and produce tabular and graphical results. The output files allowed for the scripting of sensitivity analyses, various power scenarios, and COA analyses. RFarchitect is capable of both ingesting antenna patterns, measured or modeled, or calculate antenna patterns in Statistical Antenna Gain (STATGAIN) (see **Section 6.6.2**) utilizing minimal specifications.

6.4 Link Budget

A link budget was used to calculate the potential electromagnetic interference (EMI) from each 5G transmitter. The link budget answers three questions for each interferer/receiver scenario:

- What is the power of the signal emitted from an interferer?
- What are the gains and losses experienced by the signal as it travels from the interfering transmitter to the receiver?
- What are the gains and losses experienced by the signal as it is processed by the receiver?

The link budget is an expression that starts with the transmitter power and accounts for all the losses and gains experienced prior to its arrival at the receiver. For this analysis, the relevant link budget used to model the interaction between a USG system receiver and a single transmitter is:

$$P_{RX} = P_{TX} + G_{TX} + G_{RX} - FDR - L_{T\&A} - L_{ctt} - L_{bldg} - L_{NL} - L_{TDD} - L_{PM}$$

where,

$P_{RX}\ [dBm] = Received\ power\ at\ receiver\ detector$

$P_{TX}\ [dBm] = Transmit\ power\ at\ input\ port\ of\ transmit\ antenna$

$G_{TX}(\theta_1, \varphi_1)\ [dBi] =$
$Gain\ of\ transmit\ antenna\ in\ direction\ of\ the\ receive\ antenna$

$G_{RX}(\theta_2, \varphi_2)\ [dBi] =$
$Gain\ of\ receive\ antenna\ in\ direction\ of\ the\ transmit\ antenna$

$FDR\ [dB] = Frequency\ depedent\ rejection\ of\ signal\ by\ the\ receiver$

$L_{T\&A}\ [dB]$
$= Propagation\ path\ loss\ due\ to\ physical\ separation, terrain, and\ atmospheric\ effects$

$L_{ctt}\ [dB] =$
$Clutter\ loss\ as\ determined\ by\ the\ signal\ path\ from\ transmitter\ to\ receiver$

$L_{bldg}\ [dB] = Building\ penetration\ loss\ for\ indoor\ to\ outdoor\ signal\ paths$

$L_{NL}\ [dB] = Network\ loading\ factor$

$L_{TDD}\ [dB] = Time\ Division\ Duplexing\ (TDD)\ factor$

$L_{PM}\ [dB] = Polarization\ mismatch\ loss$

Please refer to **Appendix A.1.1** for additional detail.

Several terms in the link budget equation are random variables. For example, the Network loading factor for any single 5G system will range from 0% to 100% over time. Likewise, the Network loading factor for a collection of 5G systems, at any instant in time, will also range from 0 to 100%. Because the link budget values will be summed to calculate the interference power, the average value of each link budget term, in the link budget equation, can be used to calculate the average aggregate interference. Because the interference values from individual 5G transmitters are summed to calculate the aggregate interference power, the average value of each link budget term, in the link budget equation, can be used to calculate the average aggregate interference. Note that in some cases the average value for a given term in the link budget is not available. When this happens, the median value can be used as a proxy for the mean.

6.5 5G Network

DoD requested 5G parameter inputs from PATHSS TG stakeholders to assist with 5G network modeling. Inputs were received from Celona, Cable Labs, Skylark, and CTIA. In addition, obfuscated data regarding location, EIRP, etc., was received from CBRS Spectrum Access Systems (SAS) administrators regarding EIRP, antenna height, density, and breakout of indoor versus outdoor deployments as of December 19, 2022. Stakeholder input also prompted DoD to consider Low Power Scenario B, that reflects the future use case submitted by low power stakeholders, as discussed in Appendix B.

These inputs included network deployments that used Advanced Antenna Systems (AAS), as some of the COA solutions require AAS in order to be implemented. To ensure accuracy in their 5G models, the DoD team relied heavily on the ITU recommendations when the inputs from the wireless telecommunications industry differed. Additionally, the DoD team measured data from real world deployments via drive tests to compare with ITU and wireless telecommunications industry inputs.

The 5G network components modeled for this feasibility assessment include: 5G base station Inter-Site Distance (ISDs), power levels (i.e., Effective Isotropic Radiated Power or EIRP), antenna heights, antenna patterns, network loading, Time Division Duplex (TDD) configuration, building loss, and 5G emission models. DoD also utilized measured mobile network topologies to validate the choice of ISDs.[49]

ITU-R M.2101 provides recommendations on the methodology for modeling and simulating International Mobile Telecommunications (IMT) networks for use in sharing and compatibility studies. Analysis was conducted using ITU-R M.2101 recommendations and was modified to take into account information from the ITU-R Working Party 5D Chairman’s Report “Characteristics of terrestrial component of IMT for sharing and compatibility studies in preparation for WRC-23, Annex 4.4 to Working Party 5D Chairman’s Report” (hereinafter referred to as the 5D Chairman’s Report). **Figure 6.2** below provides an illustration of a realistic deployment this model emulates. This network consists of macrocells in rural, suburban, and urban communities for coverage, with microcells added for capacity needs. The actual figure from ITU-R M.2101 was edited to include microcells (outdoor and indoor) within the urban, rural, and suburban environments.

[49] Drive tests were conducted in Indianapolis, Indiana; Miami, Florida; and Cincinnati, Ohio regarding AWS-3, BRS, CBRS, and C-Band networks.

FIGURE 6.2: EDITED FIGURE FROM ITU-R M.2101 — RECOMMENDATION ITU-R M.2101-0 (02/2017); MODELING AND SIMULATION OF IMT NETWORKS AND SYSTEMS FOR USE IN SHARING AND COMPATIBILITY STUDIES.

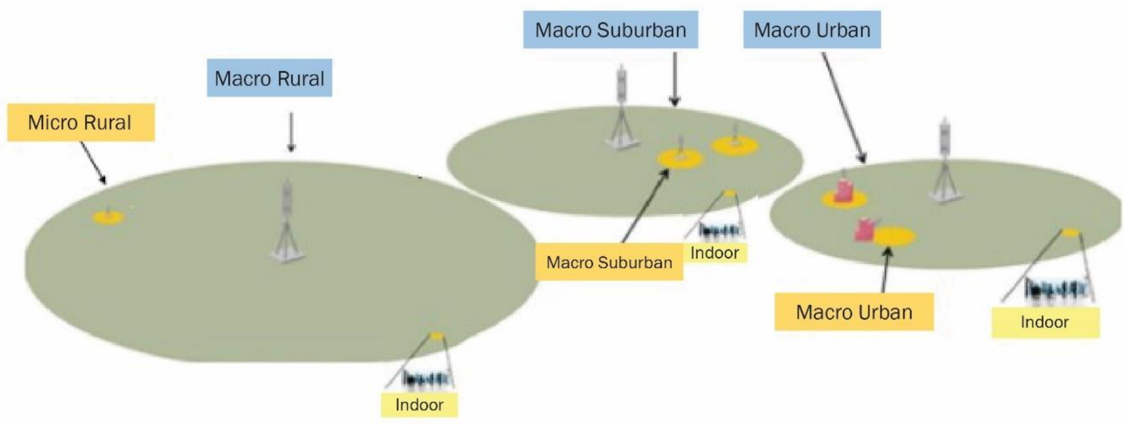

Figure 6.2: Edited Figure From ITU-R M.2101 - Recommendation ITU-R M.2101-0 (02/2017); Modeling and Simulation of IMT Networks and Systems for Use in Sharing and Compatibility Studies

Per ITU-R M.2101:

Macro Base Station Type – Mobile network served by a high-power cell site (tower, antenna, or mast). Generally, macrocells provide coverage larger than a microcell. The antennas for macrocells are mounted on ground-based masts, rooftops, and other existing structures, at a height that provides a clear view over the surrounding buildings and terrain.

Outdoor Micro Base Station Type - Outdoor mobile network served by a low or medium power cellular base station (tower), covering a limited area such as a mall, a hotel, or a transportation hub.

Indoor Micro Base Station Type - Indoor mobile network served by a low power cellular base station (tower), covering a limited area such as a mall, a hotel, or a transportation hub.

6.5.1 5G Network Base Station Deployment

The DoD team determined the best options for 5G network base station deployment by examining the modified Randomized-Real (mRR) data set, census-based deployment approach, Commerce Spectrum Management Advisory Committee (CSMAC) and ITU reports, and CBRS data.

[redacted]

The mRR laydown was selected as a basis for the macrocell 5G deployment in the 3100-3450 MHz band because it accounts for population density and there are no restrictions on sharing the data across the stakeholder community. Adjustments to the mRR were made to emulate projected future deployments in this band; including the ISD, antenna heights, power levels, microcell additions, and other factors based on wireless telecommunications industry inputs and the 5D Chairman's Report.[50] Additional factors included inputs from CBRS deployments provided by the SAS administrators. A step-by-step breakdown of the approach is described in **Appendix A.2.2**. The combination of these inputs produced the mRR+ deployment used in this analysis.

6.5.2 Environment Category Model – Based on Census Tract and Population

The original randomized real urban and rural datasets were modified to include a suburban category of devices. Based on the population of the census tract, the points would fall into one of three environments: rural, urban, or suburban, as shown below in **Table 6.1**. Specific population densities were mapped to each environment to make the determination of the census tract. Designations of suburban and urban were broken out based on ITU-R Rep. M.2415-0.

TABLE 6.1. ENVIRONMENT CLASSIFICATION		
Environment	**Population, ppsm[51]**	**Source**
FCC Rural	<100	FCC
Rural	100 – 1000	ITU 2415
Suburban	1001 – 10000	ITU 2415
Urban	>10000	ITU 2415

Table 6.1: Environment Classification

[50] ITU Radiocommunication Sector (ITU-R) Working Party 5D Chairman's Report, "Annex 4.4 – Characteristics of terrestrial component of IMT for sharing and compatibility studies in preparation for WRC-23," (June 2021), Document/716-E, 29.

Note: This 5D Chairman's Report is not publicly available and requires an ITU TIES account to access. However, it will become publicly available in an ITU report attached to WRC-23. This document is being used now to reflect assumptions consistent with US studies regarding this band.

[51] Persons per square mile.

[redacted]

[redacted]

6.5.3 5G Base Station Transmit Power

Three scenarios were examined to provide the highest fidelity in analysis. The first, a high-power scenario, was aligned with the 5D Chairman's Report and Advanced Wireless Services-1 (AWS-1), Advanced Wireless Services-3 (AWS-3), and AMBIT rulemaking. The second, a low-power scenario, uses a limited number of parameters from the CBRS rules; the Low Power B scenario, detailed in **Appendix B**, aligns with all the parameters from the CBRS rules. The third was selected as a middle point between the other two EIRPs. Additionally, for the high and mid-power scenario, the rural environment was split to allow for the increase in power allowed by the FCC in sectors with census tracts with fewer than 100 ppsm.

As recommended by the 5D Chairman's Report, microcell EIRPs for non-AAS antennas were evaluated at 29 dBm for outdoor and 24 dBm for indoor. Additionally, the microcell EIRPs were modeled as PSD, as recommended by CBRS rulemaking. This is a dual uses model derived from multiple industry inputs, real world deployments may differ. It is recognized that commercial deployments will continue to evolve. Parameters used in the high-, mid-, and low-power scenarios are listed below in **Tables 6.2, 6.3, 6.4 and 6.5**, respectively.

[redacted]

TABLE 6.2. HIGH-POWER SCENARIO		
Base Station Type	**Environment**	**Power, dBm/10 MHz**
Macro	FCC Rural	75
	Rural/Suburban/Urban	72
Outdoor Micro	Urban	29 max; use CBRS distribution for urban microcells
	Suburban	29 max; use CBRS distribution for suburban microcells
	Rural/FCC Rural	29 max; use CBRS distribution for rural microcells
Indoor Micro	Urban	24 max; use CBRS distribution for urban microcells
	Suburban	24 max; use CBRS distribution for suburban microcells
	Rural/FCC Rural	24 max; use CBRS distribution for rural microcells

Table 6.2: High-Power Scenario

TABLE 6.3. MID-POWER SCENARIO

Base Station Type	Environment	Power, dBm/10 MHz
Macro	FCC Rural	61
	Rural/Suburban/Urban	58
Outdoor Micro	Urban	29 max; use CBRS distribution for urban microcells
	Suburban	29 max; use CBRS distribution for suburban microcells
	Rural/FCC Rural	29 max; use CBRS distribution for rural microcells
Indoor Micro	Urban	24 max; use CBRS distribution for urban microcells
	Suburban	24 max; use CBRS distribution for suburban microcells
	Rural/FCC Rural	24 max; use CBRS distribution for rural microcells

Table 6.3: Mid-Power Scenario

TABLE 6.4. LOW-POWER SCENARIO A		
Base Station Type	**Environment**	**Power, dBm/10 MHz**
Macro	FCC Rural	47
	Rural/Suburban/Urban	47
Outdoor Micro	Urban	29 max; use CBRS distribution for urban microcells
	Suburban	29 max; use CBRS distribution for suburban microcells
	Rural/FCC Rural	29 max; use CBRS distribution for rural microcells
Indoor Micro	Urban	24 max; use CBRS distribution for urban microcells
	Suburban	24 max; use CBRS distribution for suburban microcells
	Rural/FCC Rural	24 max; use CBRS distribution for rural microcells

Table 6.4: Low-Power Scenario A

As modeling options were considered and feedback was received that suggested alternative approaches, sensitivity analyses were performed to inform decisions and determine the sensitivity of the results on inputs / configuration choices. [redacted] Since this was a sensitivity study, there are no results for each system/site in the Slick Sheets Appendix, but sensitivity study results are provided in **Chapter 6, Appendix** B.

[redacted]

Distributions based on CBRS deployments as of December 19, 2022 were utilized to determine the EIRPs and provide variability in microcell EIRP. Refer to **Appendix B** for a detailed breakdown.

As recommended by the 5D Chairman's Report, one microcell, statically deployed, was used and densification adjustments were made to the macrocell model for mid-power and low-power scenarios in which transmitters would be deployed with shorter ISDs. Densification adjustment factors for each power level are listed below in **Table 6.6**. Refer to **Section 6.5.4 and Appendix B** for a detailed breakdown.

This value is added to the EIRP for each corresponding transmitter, as shown below in **Table 6.6**.

TABLE 6.6. DENSIFICATION ADJUSTMENT FOR MID- AND LOW-POWER SCENARIOS			
	High-Power Scenario	**Mid-Power Scenario**	**Low-Power Scenario**
Densification Adjustment Factor (dB)	0	2.499	4.998

Table 6.6: Densification Adjustment for Mid- and Low-Power Scenarios

6.5.4 Inter-Site Distances (ISD)

While using the mRR laydown as a representative deployment, additional considerations were taken into account in regard to ISD for the updated mRR+ macrocell laydown for this effort. Since AAS antennas are being implemented in this analysis, the mRR+ ISDs were adjusted to meet the recommendations in the 5D Chairman's Report.[52]

Inputs from **Table 6.1** in the 5D Chairman's Report were used below in **Table 6.7**. These inputs aligned with the data received from CTIA for Mobile Broadband (mBB) deployments. Inputs from other companies did not meet use case requirements and were not considered for this mBB deployment.

[52] ITU Radiocommunication Sector (ITU-R) Working Party 5D Chairman's Report, "Annex 4.4 – Characteristics of terrestrial component of IMT for sharing and compatibility studies in preparation for WRC-23," (June 2021), Document/716-E, 29.

TABLE 6.7. DEPLOYMENT-RELATED PARAMETERS FOR BANDS BETWEEN 3 AND 6 GHz

	Rural	Urban/Suburban Macro	Small Cell (Outdoor)/ Microcell	Indoor (Small Cell)
Cell Radius / Deployment Density (AAS)	1.6 km / isolated BSs or a cluster of four BSs with the density of 0.001-0.006 BSs/km^2	Typical cell radius 0.4 km urban / 0.8 km suburban (10 BSs/km^2 urban / 2.4 BSs/km^2 suburban	1-3 per urban macrocell <1 per suburban macrosite	Depending on indoor coverage/ capacity demand

Table 6.7: Deployment-Related Parameters for Bands between 3 and 6 GHz[53]

The EMBRSS team used the ITU recommended ISD values for 800 meters (m), 1.6 kilometers (km), and 3.2 km for urban, suburban, and rural respectively **(Tables 6.8 and 6.9)**. These ISDs are recommended for macrocell deployments that make use of AAS at high power, one of three power scenarios analyzed in this analysis.

TABLE 6.8. DEPLOYMENT-RELATED PARAMETERS FOR BANDS BETWEEN 3 AND 6 GHZ

Environment	ISDs, km
Urban	0.8
Suburban	1.6
Rural/FCC Rural	3.2

Table 6.8: Deployment-Related Parameters for Bands between 3 and 6 GHz

[53] *Id.*

[redacted]

TABLE 6.9. ISD PER SCENARIO

Environment	High-Power ISD (km)	Mid-Power ISD (km)	Low-Power ISD (km)
Rural/FCC Rural	3.2	2.4	1.8
Suburban	1.6	1.2	0.9
Urban	0.8	0.6	0.45

Table 6.9: ISD per Scenario

Please refer to **Appendix B** for a detailed breakdown of this section. The modified randomized real deployment (mRR) was used as the basis to build a nationwide 5G network. This mRR deployment represents a network macro cells. Adjustments and additions were made to the mRR deployment with respect to ISD, antenna heights, EIRPs, and antenna types per 5D Chairman's Report "Characteristics of terrestrial component of IMT for sharing and compatibility studies in preparation for WRC-23, Annex 4.4 to Working Party 5D Chairman's Report."[54] Macro cells were not introduced or removed from the mRR deployment in order to ensure consistency with industry population density requirements. Microcells were then added to the mRR deployment per recommendations from the 5D chairman's report along with inputs from the CBRS deployment provided by the SAS administrators. In an actual deployment there could be more or fewer base stations in a given area based on zoning and other factors.

6.5.5 Macro/Microcell Ratio

Once the macro deployment was built, the DoD team implemented ISD values ranging from 100m to 600m as recommended by industry input and microcell to macrocell ratios consistent with **Table 6.1** of the 5D Chairman's Report (1-3 microcells per urban macrocell (sector) and <1 per urban macrosite).

Referencing **Table 6.1** from the 5D Chairman's Reportagain, the model proposes 1-3 microcells per urban macrocell (sector) and <1 per urban macrosite which is in line with CTIA input. [55]

There are no ITU recommendations made for rural microcell deployments. As such, rural macro to micro ratios were derived from CBRS data provided by SAS vendors. **Table 6.10** breaks down the micro to macrocell deployment. Please refer to **Appendix B** for additional information.

[54] *Id.*

[55] *Id.*

[redacted]

TABLE 6.10. MICROSITE DEPLOYMENT OVERVIEW		
Microcells	**Environment**	**Ratios**
Outdoor	Urban	3 microcells per urban macrocell
	Suburban	1 microcell per suburban macrocell
	Rural/FCC Rural	0.32 microcell per rural macrocell
Indoor	Urban	3 microcells per urban macrocell
	Suburban	1 microcell per suburban macrocell
	Rural/FCC Rural	0.32 microcell per rural macrocell

Table 6.10: Microsite Deployment Overview

6.5.6 5G Antennas

Per the 5D Chairman's Report,[56] **Table 6.11** provides recommendations on how AAS and non-AAS antennas should be modeled. Since the macro antennas make use of AAS, they have been modeled as three sectors with peak 25 dBi gain. The max gain selected for this feasibility assessment, at every azimuth-elevation angle for the AAS, corresponds to the mean value of the corresponding CDF generated by a Monte Carlo simulation. These values are 14.4, 15.7, and 17.6 for urban, suburban, and rural, respectively. This will be addressed in further detail below. The microcells are modeled per ITU F.1336 as omnidirectional antennas with gains of 0 and 5 dBi for indoor and outdoor, respectively. These inputs lined up closely with all wireless telecommunications industry inputs from a non-AAS perspective and matched CTIA inputs.

AAS and non-AAS antenna parameters were solicited in order to leave open the possibility of modeling 4G and 5G networks, potentially separately or together. The decision to focus on 5G networks, for macrocells, include:

- Acknowledgement that 5G systems can support a larger space of COAs since COA #1 and aspects of CoA #2 are beyond 4G BS capability (COAs defined in **Section 6.13**). Therefore, if 4G macrocells are enabled in this band sharing mechanisms, then they would be more stringent/limited, and any interference budget would have to be apportioned between 4G and 5G systems.

- Assumption that only 5G systems (and beyond) would occupy this band

6.5.6.1 Macrosite AAS

[56] *Id.*

[redacted]

As shown below in **Figure 6.3**, the 5G modeling approach is designed to support Monte Carlo simulations offline prior to RFarchitect execution. In particular, the Monte Carlo simulations aggregate statistics of transmission gains using coarse Synchronization Signal Block (SSB) beams and refined shared channel beams for a specific sector parameterization. These statistics can be used to create a static 3D radiation pattern. This 3D radiation pattern then serves as the antenna model for the interfering 5G base stations. This process can be repeated for a number of specific sector parameterizations to generate unique 3D radiation patterns per parameterization which can be associated with different types of sectors within an RFarchitect deployment. A detailed explanation for the development of the AAS antenna is explained in **Appendix B.**

Monte Carlo Simulation Framework

Selection of a category model (macro suburban, urban, rural) defines relevant 5G base station system and antenna parameters, User Equipment (UE) parameters such as the UE distribution used to randomly sample UEs in 3D space, and the channel model used to generate Multiple-Input Multiple-Output (MIMO) channel realizations. For each Monte Carlo run, a simulation stores the UE-specific 3D radiation pattern corresponding to the Precoding Matrix Indicator (PMI) value reported by each active UE. In practice, the PMI value is used by the base station to precode a UE’s Physical Data Shared Channel (PDSCH) transmission.

At the end of a specified number of Monte Carlo runs, aggregate statistics are calculated based on the stored 3D radiation patterns to describe the base station transmission gain over a regular spatial grid. Included in the aggregate statistics are the 3D radiation patterns corresponding to the SSB transmission using the coarse beams, and are implicitly weighted by their periodicity (every 20 ms) in the simulation.
UE location sampling and SSB acquisition, CSI measurement, and aggregate statistics generation are detailed in **Appendix B**.

[redacted]

[redacted]

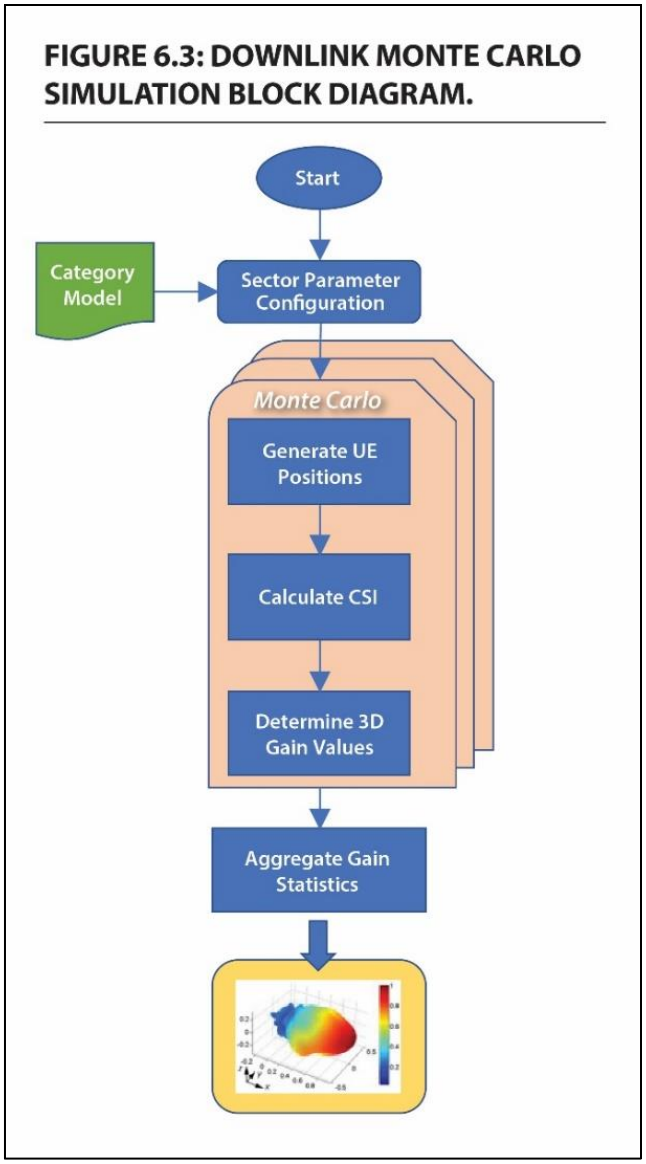

Figure 6.3: Downlink Monte Carlo Simulation Block Diagram

[redacted]

[redacted]

3D Antenna Patterns

The 3D antenna patterns for the urban, suburban, and rural/FCC rural category models are presented in **Figures 6.4-6.6**. The max gain selected for this study, at every azimuth-elevation angle for the AAS, corresponds to the mean value of the corresponding CDF generated by a Monte Carlo simulation. These values are 14.4, 15.7, and 17.6 for urban, suburban, and rural, respectively. These patterns serve as the antenna patterns for the urban, suburban, and rural sectors in the RFarchitect deployment.

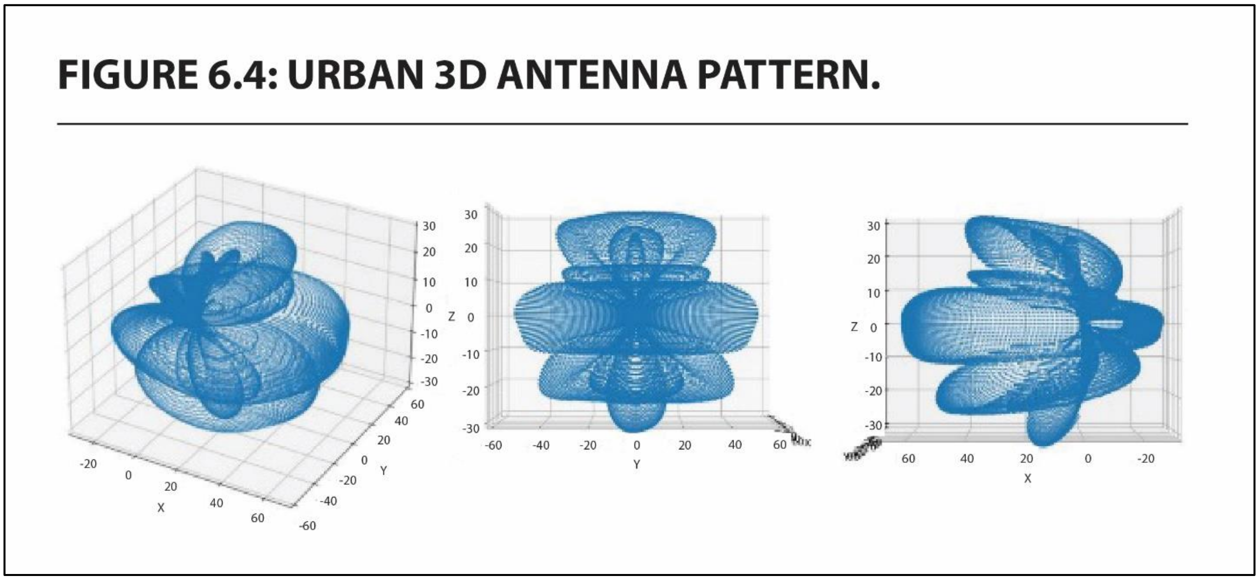

Figure 6.4: Urban 3D Antenna Pattern

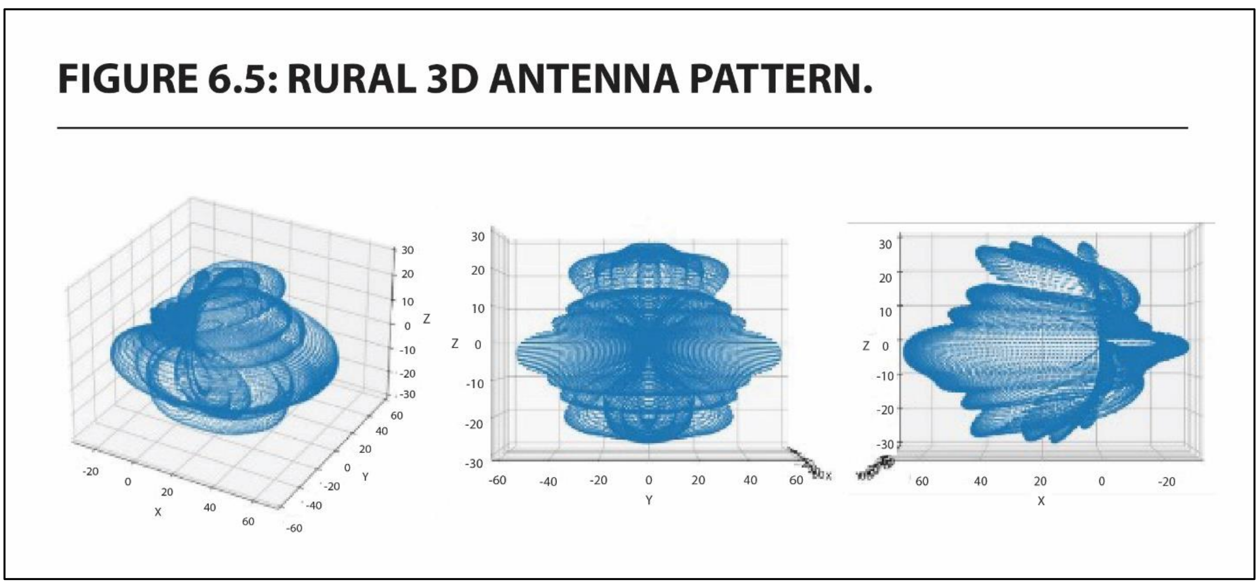

Figure 6.5: Rural/FCC Rural 3D Antenna Pattern

[redacted]

[redacted]

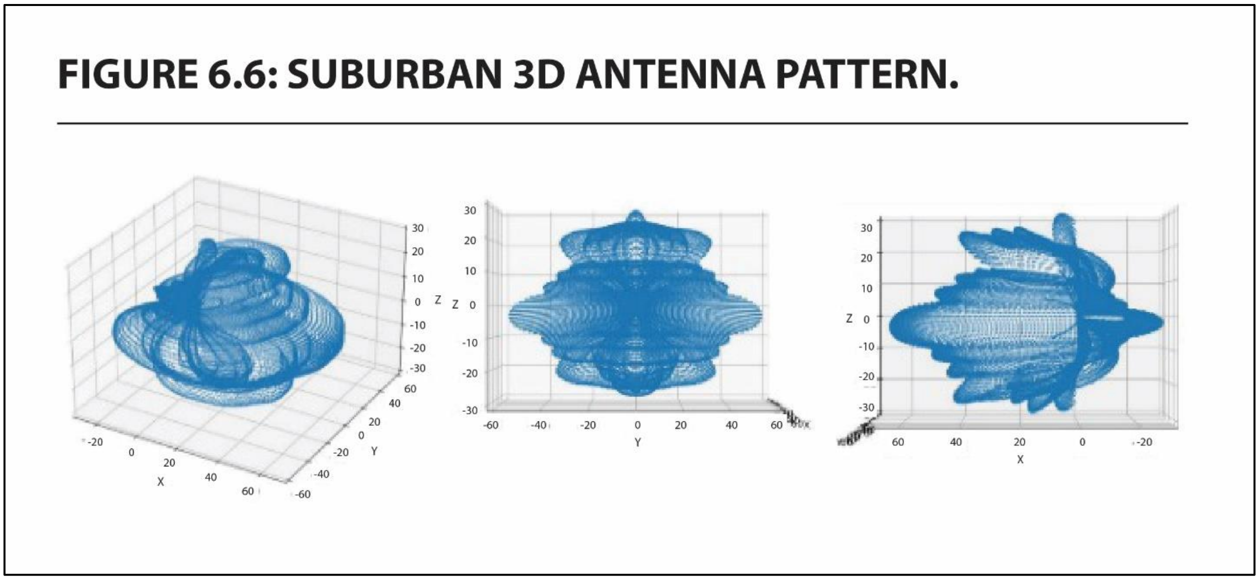

Figure 6.6: Suburban 3D Antenna Pattern

Microsite Omnidirectional

For the microsites, recommendation ITU-R F.1336 was used. These antennas were modeled as omnidirectional with a gain of 0 dBi for the micro indoor devices, and 5 dBi for the micro-outdoor devices. The microsites were primarily included for close range transmissions, also known as “hot spots,” and therefore high-gain directional antennas were not necessary for this use case.

The antenna patterns for both indoor and outdoor cells are plotted below in **Figures 6.7 and 6.8**.

[redacted]

[redacted]

FIGURE 6.7: 0 DBI OMNI ANTENNA USED FOR INDOOR MICROCELLS.

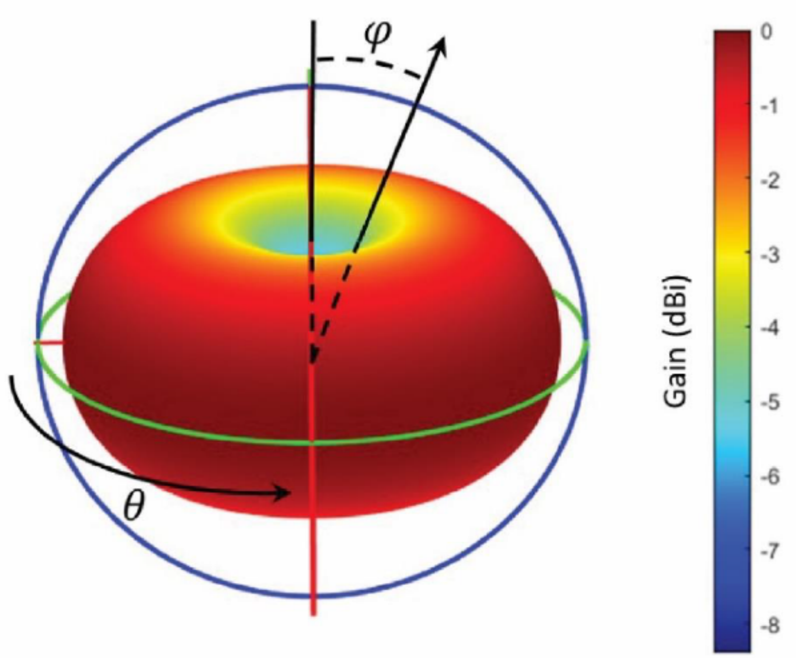

Figure 6.7: 0 dBi Omni Antenna Used for Indoor Microcells

FIGURE 6.8: 5 DBI OMNI ANTENNA USED FOR OUTDOOR MICROCELLS.

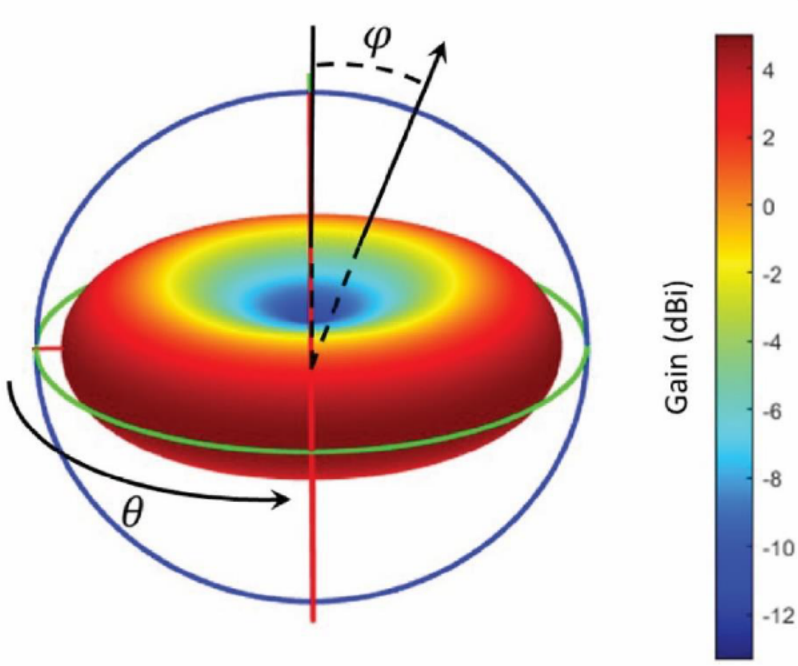

Figure 6.8: 5 dBi Omni Antenna Used for Outdoor Microcells

6.5.7 Downtilts

[redacted]

6.5.7.1 AAS Macrocell

Both the rural and suburban parameterizations include a mechanical antenna down-tilt of 0-degrees. The rural and suburban antenna models use a 3-3-2 and 3-2 coarse beam configuration, respectively. Each coarse beam is electronically tilted to provide coverage across the sector. The electronic tilt is imposed per coarse SSB beam and is fixed per "row" (since all beams in the same "row" have the same electronic tilt and only vary in azimuth). So, the top row of three beams in the 3-2 configuration all have the same electronic tilt, and the row of two beams have the same electronic tilt. The same logic applies to the 3-3-2 coarse beam configuration. For rural (3-3-2) and suburban (3-2), the top and middle rows have the same electronic tilt of 3 degrees and 6 degrees, respectively. The bottom two beams in the rural 3-3-2 configuration have a 10-degree electronic tilt. Additionally, the rural antenna height is larger than the suburban antenna height. Therefore, the increased transmit antenna height in the rural category model provides the increased coverage range for the same electronic tilts when comparing to the suburban category model.

There is no electronic tilt for the urban category model because there is no precoding on the SSB, so no coarse beam configuration is used. This configuration, in conjunction with the 8x2 logical port configuration, is well suited to provide both coverage and capacity for the smaller urban macro sector size.

6.5.7.2 Non-AAS Microcell

While the AAS antennas required a combination of electrical and mechanical downtilts, the micro antennas were omnidirectional with no downtilts necessary.

Table 6.11 compiles each environment and antenna type downtilts.

TABLE 6.11. ANTENNA TYPES AND DOWNTILTS				
Environment	**Antennas**	**Mechanical Downtilt**	**Electrical Downtilt**	**Notes**
Macro Rural/FCC Rural	3-3-2 AAS	0	3, 6, 10	Top row: 3 degree electrical downtilt Middle row: 6 degree electrical downtilt Bottom row: 10 degree electrical downtilt
Macro Suburban	3-2 AAS	0	3, 6	Top row: 3 degree electrical downtilt Bottom row: 6 degree electrical downtilt

TABLE 6.11. ANTENNA TYPES AND DOWNTILTS

Environment	Antennas	Mechanical Downtilt	Electrical Downtilt	Notes
Macro Urban	AAS	6	0	
Micro Outdoor Urban	Omni	0	0	
Micro Outdoor Suburban	Omni	0	0	
Micro Outdoor Rural/FCC Rural	Omni	0	0	
Micro Indoor Urban	Omni	0	0	
Micro Indoor Suburban	Omni	0	0	
Micro Indoor Rural/FCC Rural	Omni	0	0	

Table 6.11: Antenna Types and Downtilts

6.5.8 Antenna Heights

Like previous deployment characteristics, wireless telecommunications industry inputs were referenced to help model antenna heights. For this input, the macro and microsite height inputs aligned with the 5D Chairman's Report.[57]

Per the 5D Chairman's Report, antenna heights for AAS systems commensurate with the High Power 5G Deployment Scenario for each environment are shown below in **Table 6.12**:

[57] *Id.*

[redacted]

TABLE 6.12. DEPLOYMENT-RELATED PARAMETERS FOR BANDS BETWEEN 3 AND 6 GHz				
	Rural Macrocell	**Urban/Suburban Macrocell**	**Outdoor Microcell**	**Indoor Microcell**
Antenna Height	35m	20m Urban / 25m Suburban	6m	3m

Table 6.12: Deployment-Related Parameters for Bands between 3 and 6 GHz[58]

Recommendations were provided by Celona, Cable Labs, Skylark, and CTIA for macrocells, outdoor microcells, and indoor microcells heights. For indoor microcells, the distribution of heights from CBRS (see Appendix A.2.3.2) were utilized to provide more accuracy by considering people in a building taller than one story that would be up higher than the 3m provided in the table above.

Table 6.13 provides a breakdown of macro and microcells, with both indoor and outdoor heights, for the high, mid, and low-power scenarios.

As the transmit power decreases, there is a need to lower the antenna heights accordingly for modeling purposes. For the high and mid-power scenarios, it was assumed that the antenna heights would remain consistent with each other (35m, 25m, and 20m).

For the low-power scenario, the CBRS data was investigated to understand the average outdoor base station height. The rationale was to incorporate real data, considering that CBRS base stations transmit at max power of 47 dBm/10MHz, and therefore should align with heights representative of those EIRPs. Based on the CBRS data received, the average heights for transmitters at 47 dBm/10MHz were 15m for rural, 24m for suburban, and 21m for urban. Note: In CBRS data a considerable number of rural devices were fixed Customer Premises Equipment (CPEs).

Refer to **Appendix B** for a more detailed approach.

TABLE 6.13. MACRO AND MICROCELL ENVIRONMENT BREAKDOWN				
	Environment	**High Power Heights, m**	**Mid Power Heights, m**	**Low Power Heights, m**
Macro	Rural/FCC Rural	35	35	15
	Suburban	25	25	24
	Urban	20	20	21

[58] *Id.*

[redacted]

TABLE 6.13. MACRO AND MICROCELL ENVIRONMENT BREAKDOWN				
	Environment	**High Power Heights, m**	**Mid Power Heights, m**	**Low Power Heights, m**
Outdoor Micro	Urban	6		
	Suburban	6		
	Rural/FCC Rural	6		
Indoor Micro	Urban	5, 10, 21, etc. use CBRS distribution for urban microcells		
	Suburban	5, 10, 15, etc. use CBRS distribution for suburban microcells		
	Rural/FCC Rural	5, 10, 15, etc. use CBRS distribution for rural microcells		

Table 6.13: Macro and Microcell Environment Breakdown

6.5.9 User Equipment (UE) Monte Carlo Simulation

A comparative analysis between commercial 5G wireless uplink and downlink emissions was conducted to determine whether User Equipment (UE) emissions would have a material impact on the results. The approach used for the comparison included:

- For an urban, a suburban, and a rural environment:
  - Use a Monte Carlo simulation to assist in assessing the mean of the total uplink emission for a three-sector site. The assessment includes UE EIRP, building exit loss, clutter loss, network loading, and TDD uplink duty cycle.
  - Use the link budget parameters in **Section 6.4** to determine the mean total downlink emission, for a three-sector site. The assessment includes downlink EIRP at two antenna azimuthal orientations, clutter loss, network loading, and TDD Factor duty cycle.
  - Compare the two values for each environment to see if a higher fidelity model that includes microcells or other improvements is warranted.
  - Refine the assessments as needed.

6.5.9.1 Uplink

The aggregate interference assessment performed as part of the EMBRSS feasibility assessment in the 3100 - 3450 MHz band focuses on downlink emissions as the sole source of interference to incumbent receivers, operating under the assumption that the corresponding uplink emissions do not meaningfully contribute to the aggregate interference calculation. While it is correct to assume in general that uplink emissions will amount to less interference than downlink emissions, the reduced spatial dependence of uplink as compared to downlink may present scenarios where uplink emissions should be included in the aggregate interference calculation. The analysis described here focuses on evaluating the uplink emissions of a single sector for comparison with downlink emissions, leveraging a UE-based simulation framework to generate a Cumulative Distribution Function (CDF) of the total uplink power leaving a sector. This total uplink power leaving the sector, termed the uplink "exit" power, quantifies the radiated uplink power for a single sector in a given slot. This value accounts for building exit losses and endpoint clutter at the UE transmitter and serves as the comparative value with downlink power.

The uplink simulation framework focuses on the determination of aggregate uplink power per slot for a single sector. The simulation framework consists of three primary functional components:

- **Random UE Sampling**: random sampling of 3D UE locations, per slot, based on a configured UE distribution.

- **Statistical Channel Modeling and Path Loss Calculation:** generation of channel realizations between the Base Station (BS) and a UE to determine the corresponding path loss of the link.

- **Power Control evaluation and Aggregate Exit Power (Radiated Power) Calculation:** evaluation of the uplink power control equation based on calculated path loss and system parameterization, from which the aggregate uplink power "leaving the sector" is calculated.

The "Random UE Sampling" component—in conjunction with the "Statistical Channel Modeling and Path Loss Calculation" component—form the basis from which the uplink power control equation is evaluated and, subsequently, an individual UE's transmit power is calculated. For each individual UE transmit power calculated, a corresponding UE exit power is calculated by application of a clutter loss term. The UE exit power represents the UE's transmitted power "leaving the sector." Given all active UE exit powers in a slot, an aggregate uplink power calculation is performed by summing all the active UE exit powers to determine the so-called uplink power "leaving the sector." The Monte Carlo simulation repeats these calculations for a specified number of slots, or runs, to determine the CDF describing the total uplink power leaving the sector. The high-level block diagram of the uplink Monte Carlo simulation is shown in **Figure 6.9.** The relevant procedures and input parameters are described in detail in **Appendix B.**

[redacted]

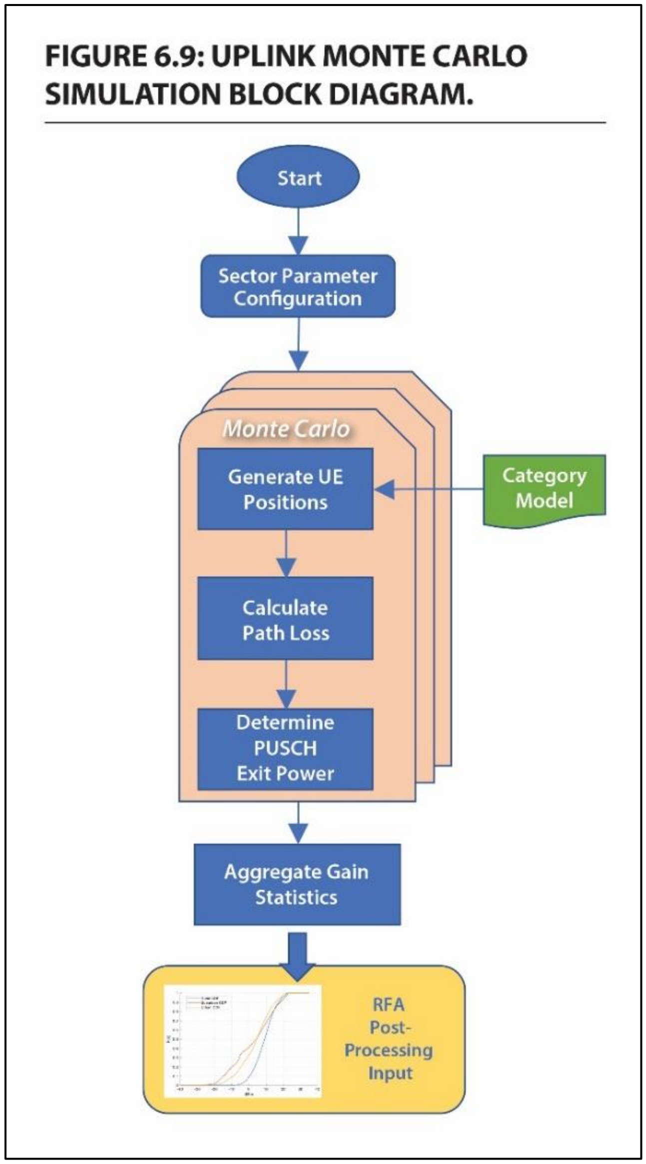

Figure 6.9: Uplink Monte Carlo Simulation Block Diagram

The total exit power CDFs for the urban macro, suburban macro, and rural macro sector configurations are presented in **Figure 6.10**. **Table 6.13** presents the mean total exit power for each sector configuration. The mean total exit power is calculated from the total exit power CDFs by first deriving the probability distribution function (PDF). The mean value is then calculated as a weighted discrete sum over the range of power values, where the weights are the corresponding probability values from the PDF. As expected, the distribution for the urban macro sector configuration indicates the smallest mean total exit power of 9.93 dBm as compared to the rural and suburban macro configurations. The rural and suburban macro mean total exit powers are extremely similar at 12.17 and 12.21 dBm, respectively. In the rural macro configuration, the total exit powers are largely dominated by the large sector sizes, so UEs simply require additional power to compensate for increased path losses, even given an increase in probability of Line of Sight (LOS) links. In contrast, the suburban macro configuration is dominated by a decrease in probability of LOS links, so larger UE exit powers are a function of

[redacted]

[redacted]

an increase in path losses from Non-Line of Sight (NLOS) links.

FIGURE 6.10: CDF OF TOTAL EXIT POWER LEAVING EACH SECTOR.

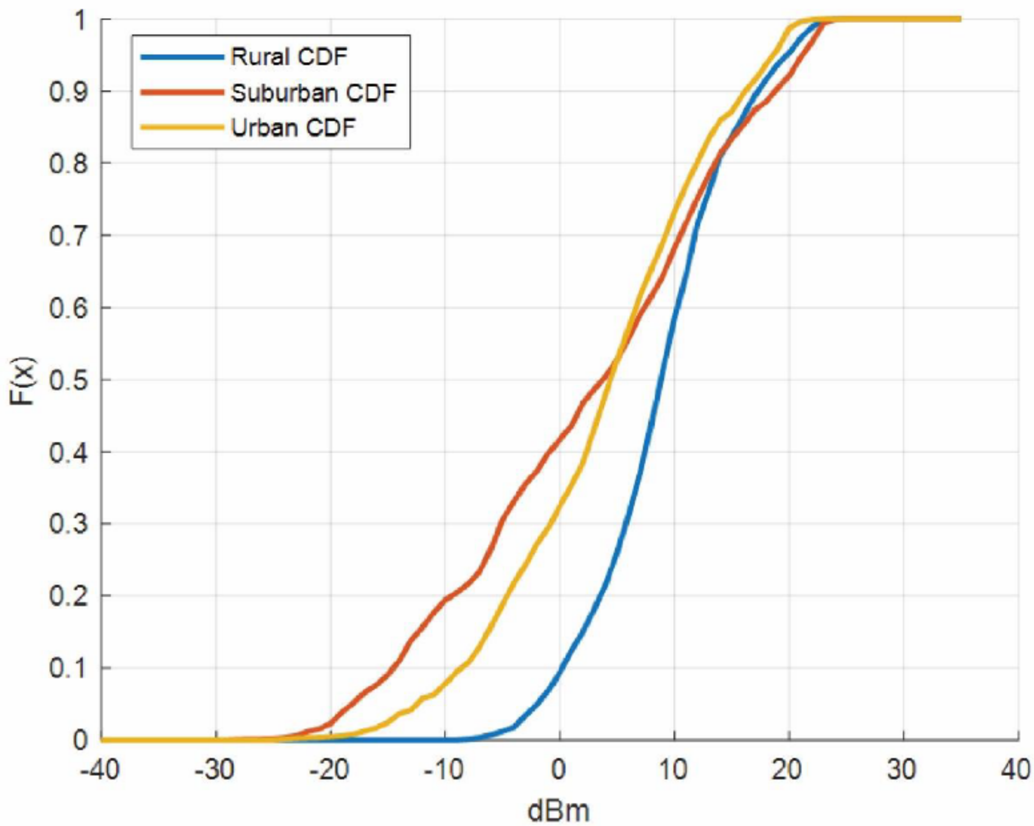

Figure 6.10: CDF of Total Exit Power Leaving Each Sector

TABLE 6.14. SUMMARY TABLE WITH MEAN OF TOTAL EXIT POWER LEAVING EACH SECTOR	
Sector Configuration	**Mean Total Exit Power [dBm]**
Urban Macro	9.93
Suburban Macro	12.21
Rural Macro	12.17

Table 6.14: Summary Table with Mean of Total Exit Power Leaving Each Sector

[redacted]

6.5.9.2 Downlink Laydown

The downlink assessments use the link budget parameters in **Appendix B.1.1** and consider two base station sites with different sector-pointing orientations with respect to a USG receiver, as shown in **Figure 6.11**. Note that the location of the USG receiver is illustrative and does not represent a specific laydown or geometry. The orientation of Base Station Site #1 is such that the USG receiver is at the bore site of sector 1, with sectors 2 and 3 facing partially away. The orientation of Base Station Site #2 is such that the USG receiver is at the edge of sectors 5 and 6, with sector 4 pointing directly away from the USG receiver. The 2 orientations are representative of 2 adjacent base station sites attempting to minimize inter-cell interference under universal frequency reuse. The 6 total sectors form a continuum of possible sector-to-USG receiver orientations from a worst case to best case scenario with regard to interference to the USG receiver.

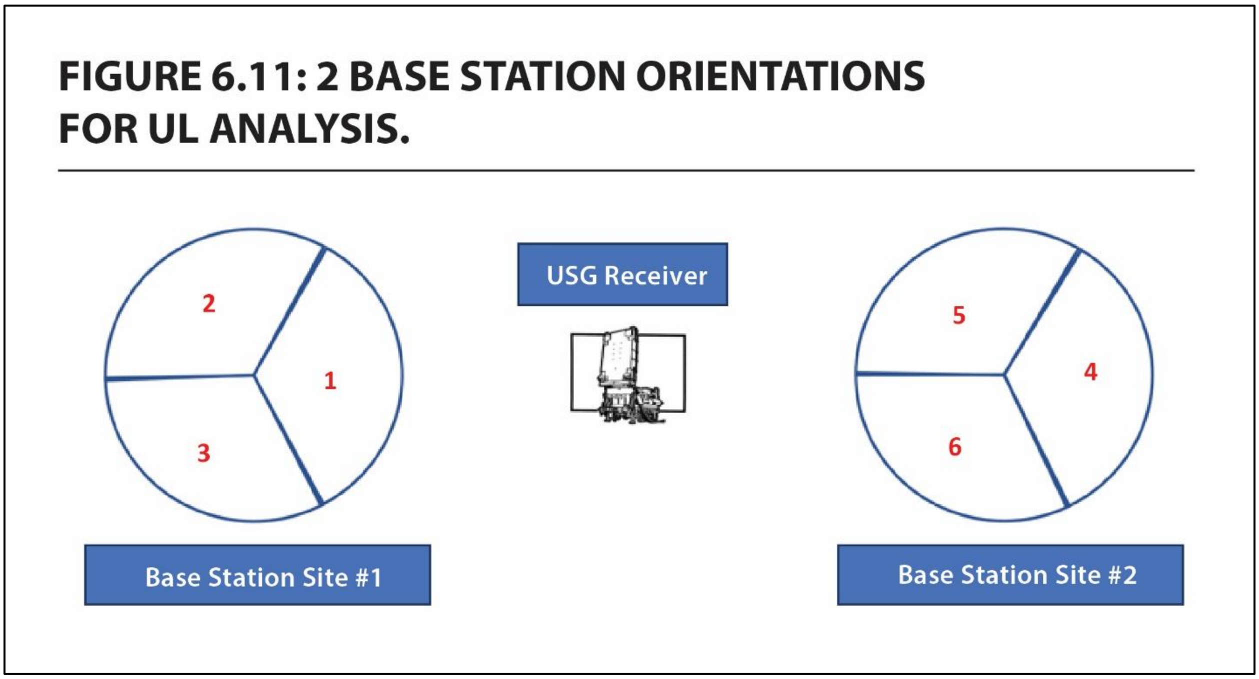

Figure 6.11: Two Base Station Sites with Different Sector-Pointing Orientations with Respect to a USG Receiver

To determine if modeling the interference from the uplink will have a material impact on the aggregate interference, the aggregate power leaving each of the above Base Station Site orientations is calculated with and without uplink power included and the corresponding delta in power for each orientation is determined. Note that the downlink power calculated is a function of the individual sector orientations for each Base Station Site relative to the USG receiver. Implicit in this analysis is the assumption that uplink and downlink emissions leaving a sector will experience identical propagation environments in a TDD deployment.

6.5.9.3 Uplink (UL) Comparison Results

Table 6.15 provides the intermediate values of the downlink power comparison. The 'Downlink Base Station Site #1' column provides the total downlink power for Base Station Site #1 for each scenario under evaluation. Similarly, the 'Downlink Base Station Site #2' column provides the total downlink power for Base Station Site #2 for the same scenarios. The 'Uplink' column provides the total 3-sector uplink power by summing the values as defined in **Table 6.14** three times and decrements the total by 6.02 dB to account for an uplink TDD duty cycle of 25%. Observe that the uplink power leaving each base station site is assumed to be equal. The 'Total Base Station Site #1' and 'Total Base Station Site #2' columns provide the total power leaving each Base Station Site including uplink power, respectively. The 'Delta Base Station Site #1' and 'Delta Base Station Site #2' columns provide the difference in total power leaving each respective Base Station Site when uplink is included in the total and when it is not.

As expected, the inclusion of uplink power in the High-Power scenario yields a negligible difference in total powers, as evidenced by 0 dB deltas for both Base Station Sites. The maximum difference, 0.20 dB, occurs in the urban low-power scenario with orientation #2 and clearly demonstrates that uplink modeling will not have a material impact on the feasibility assessment results.

TABLE 6.15. INTERMEDIATE TOTAL POWER VALUES FOR BASE STATION SITE #1 AND BASE STATION SITE #2								
		Downlink Base Station Site #1 (dBm/10 MHz)	**Downlink Base Station Site #2 (dBm/10 MHz)**	**Uplink (dBm/10 MHz)**	**Total Base Station Site #1 (dBm/10 MHz)**	**Total Base Station Site #2 (dBm/10 MHz)**	**Delta Base Station Site #1 (dB)**	**Delta Base Station Site #2 (dB)**
High Power	Urban	49.06	48.54	10.28	49.06	48.54	0.00	0.00
	Suburban	53.90	52.34	12.46	53.90	52.34	0.00	0.00
	Rural	55.87	52.63	12.19	55.87	52.63	0.00	0.00
Mid Power	Urban	35.06	34.54	10.28	35.07	34.56	0.01	0.02
	Suburban	39.90	38.34	12.46	39.90	38.35	0.01	0.01
	Rural	41.87	38.63	12.19	41.88	38.64	0.00	0.01
Low Power	Urban	24.06	23.54	10.28	24.24	23.74	0.18	0.20
	Suburban	28.90	27.34	12.46	28.99	27.48	0.10	0.14
	Rural	30.87	27.63	12.19	30.93	27.75	0.06	0.12

Table 6.15: Intermediate total power values for Base Station Site #1 and Base Station Site #2

0
1

6.5.10 5G Emission Power Spectral Density (PSD) Curve

The EMBRSS PSD curve will likely be defined in a similar manner to the FCC 3450-3550 MHz (AMBIT) service rules.[59] It is affected by the in-band emission limits of 75 dBm/10MHz in FCC-defined rural environments and 72 dBm/10MHz in rural (100-1000 ppsm), urban, and suburban as well as the adjacent channel/out-of-band limits that are based on the conducted power (-13 dBm/MHz at channel/band edge, -25 dBm/MHz at 10 MHz from band edge, -40 dBm/MHz beyond 10 MHz from band edge). This breakdown is as follows:

- Equal or less than -13 dBm/MHz limit from edge of the band to 10 MHz down (3440 MHz) and up (3560 MHz).

- Equal to or less than -25 dBm/MHz beyond the 10 megahertz offset from the band edge between 3440 and 3430 MHz and between 3560 and 3570 MHz.

- Equal to or less than -40 dBm/MHz below 3430 megahertz and above 3570 MHz.

Figure 6.12 illustrates a 5G emission measured by NTIA along with nominal power levels and FCC rules for adjacent-channel and Out-Of-Band (OOB) emission limits. This analysis assumes the same adjacent and OOB limits as the AMBIT band with a roll-off of 20 dB/decade.

[59] U.S. Federal Communications Commission, *Facilitating Shared Use in the 3100-3550 MHz Band: Second Report and Order, Order on Reconsideration, and Order of Proposed Modification*, WT Docket No. 19-348, 36 FCC Rcd 5987 (9) (March 18, 2021), https://docs.fcc.gov/public/attachments/FCC-21-32A1.pdf

[redacted]

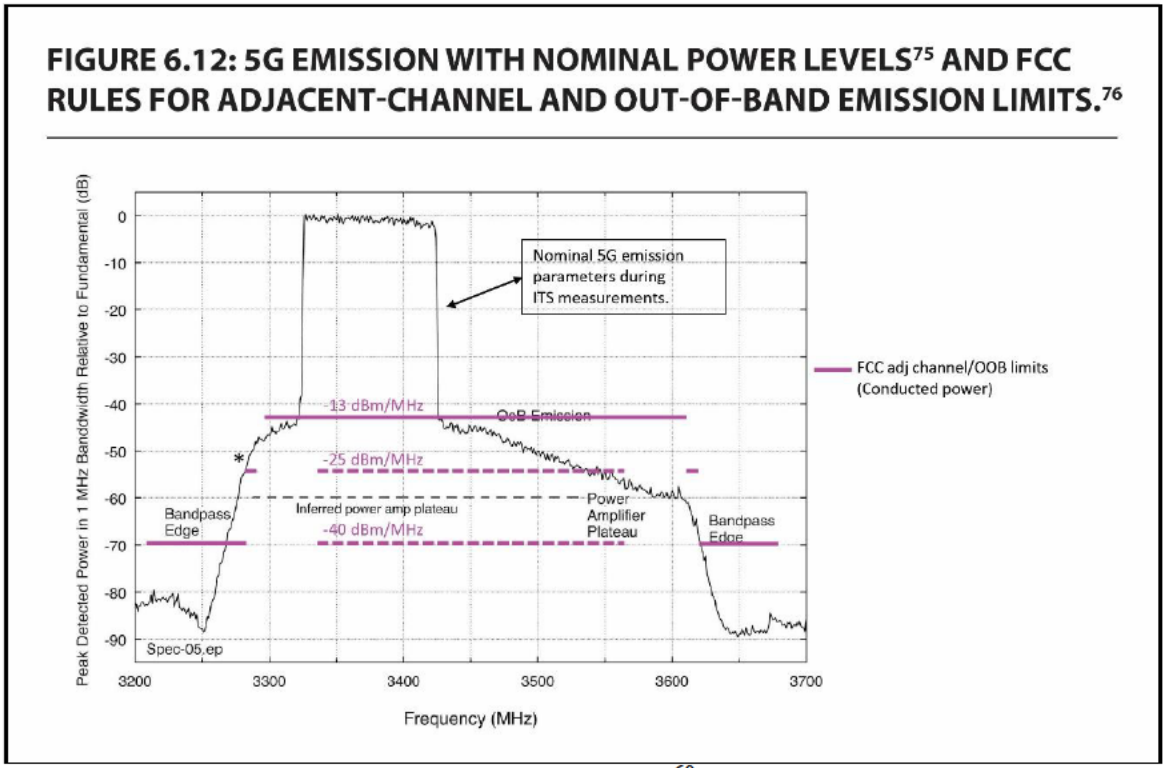

Figure 6.12: 5G Emission with Nominal Power Levels[60] *and FCC Rules for Adjacent-Channel and Out-of-Band Emission Limits*[61]

The 5G emission modeled in this analysis starts at 3100 MHz and ends at 3450 MHz. There were no guard bands modeled in between the 10 MHz 5G channels throughout the 3100-3450 MHz band. The OOB limits were modeled before the start and after the stop frequencies for adjacent band analyses per the OOB AMBIT rulemaking. This 5G emission curve is used to calculate Frequency Dependent Rejection (FDR) as described in **Section 6.8**. A full breakdown of the 5G normalized emission curves is provided in **Appendix B.5.6**.

6.5.11 Network Loading

Per 5D Chairman's Report, **Table 6.16** references network loading recommendations.

[60] U.S. Department of Commerce, National Telecommunications and Information Administration, *Measurements of 5G New Radio Spectral and Spatial Power Emissions for Radar Altimeter Interference Analysis*, NTIA Report 22-562 (October 2022), https://its.ntia.gov/umbraco/surface/download/publication?reportNumber=TR-22-562.pdf.

[61] "3.45 GHz Service," 47 C.F.R. part 27 § 53(n) (2023), https://www.ecfr.gov/current/title-47/chapter-I/subchapter-B/part-27/subpart-C/section-27.53.

[redacted]

[redacted]

TABLE 6.16. 5D CHAIRMAN'S REPORT DEPLOYMENT-RELATED PARAMETERS FOR BANDS BETWEEN 3 AND 6 GHZ				
	Rural	**Urban/Suburban Macro**	**Small Cell (Outdoor)/Microcell**	**Small Cell (Indoor)/Microcell**
Network Loading Factor (Base Station Load Probability X%)	50%	20%, 50%	20%, 50%	20%, 50%

Table 6.16: 5D Chairman's Report Deployment-Related Parameters for Bands between 3 and 6 GHz

The 5D Chairman's Report recommends a value of 20% to 50%, based on environment. Based on industry input this study considered network loading of 30%.

Considering this input, the overall factor (loss) that needs to be added to our link budget for network loading equates to 10*log (NL) = 10*log (0.30) = -5.23 dB.

6.5.12 Time Division Duplex (TDD)

Per the 5D Chairman's Report,[62] **Table 6.17** references network loading recommendations.

TABLE 6.17. DEPLOYMENT-RELATED PARAMETERS FOR BANDS BETWEEN 3 AND 6 GHZ				
	Rural (Optional, See Note A Below)	**Urban/Suburban Macro**	**Small Cell (Outdoor)/ Microcell**	**Indoor (Small Cell)**
BS TDD Activity Factor	75%	75%	75%	75%

Table 6.17: Deployment-Related Parameters for Bands between 3 and 6 GHz

This feasibility assessment considered a downlink duty cycle of 75%. Considering this input, the overall factor (loss) that needs to be added to our link budget for TDD equates to 10*log (TDD) = 10*log (0.75) = -1.25 dB.

6.5.13 Final Deployment Numbers

[62] ITU Radiocommunication Sector (ITU-R) Working Party 5D Chairman's Report, "Annex 4.4 – Characteristics of terrestrial component of IMT for sharing and compatibility studies in preparation for WRC-23," (June 2021), Document 5D/716-E, 29.

[redacted]

Based on the approach mentioned in previous sections, the model's overall deployment resulted in 174,654 total sites. The breakdown of each use case is shown in **Table 6.17**. The first column displays the difference in deployment based on the FCC definition of population/environment. The second and third columns detail the supplemental microcells that were added to align with the ITU recommendations and CBRS data for 5G deployments.

TABLE 6.18. FINAL DEPLOYMENT NUMBERS			
	Modified mRR (mRR+)	**Microcells - Outdoor**	**Microcells - Indoor**
Urban	5855	17565	5855
Suburban	30088	30088	30088
Rural	33452	10271	10392
Total	69395	58924	46335

Table 6.18: Final Deployment Numbers

Figure 6.13 is a CONUS wide view of the mRR+ deployment consisting of all 69,395 macro and 105,259 microcells.

FIGURE 6.13: CONUS WIDE VIEW OF THE MRR + DEPLOYMENT.

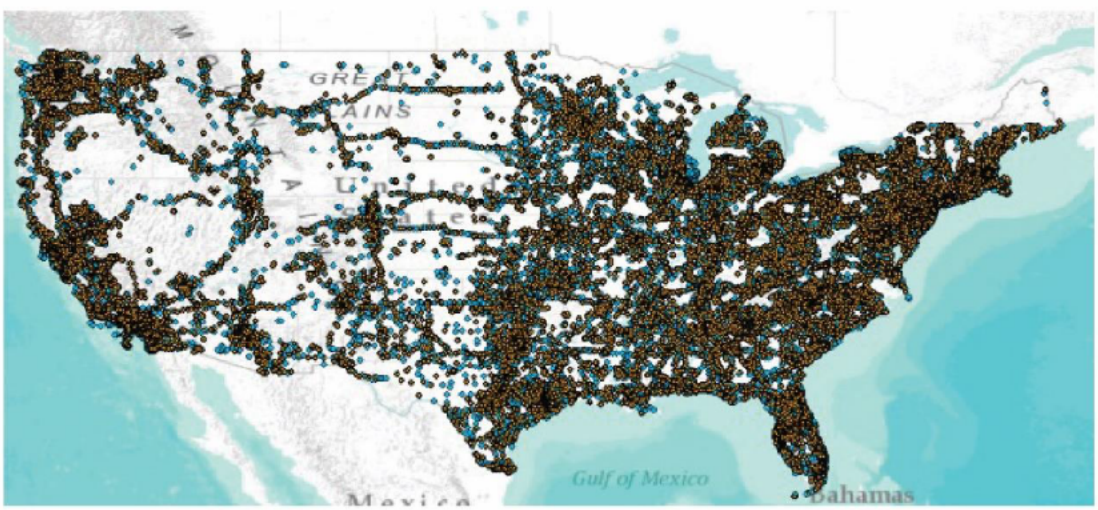

Figure 6.13: CONUS Wide View of the mRR+ Deployment

6.6 USG Systems

The systems that USG operates in the 3100-3450 MHz Band are crucial to the defense of the United States and its allies. In this band, USG operates a variety of high-powered radar systems on fixed, mobile, shipborne, and airborne platforms. These radar systems are used for air and missile defense, missile and gunfire control, bomb scoring, battlefield weapon locations, Air Traffic Control (ATC), research tools, and range safety. The USG develops, tests, and sustains these systems at both government and contractor-owned facilities. The USG continues to deploy and develop new systems in this band for operation and training worldwide. New systems may be deployed in areas not shown in this report based on the national security needs of the USG. USG systems operating in this band are high-value systems that, if hindered, present a significant operational, tactical, and strategic risk.

6.6.1 USG System Data Collection

A questionnaire was sent to each USG stakeholder requesting data on systems in and around the 3100-3450 MHz band. A list of these systems can be found in **Appendix B.33**. The output of that questionnaire was compiled and provided to DoD in the form of Operational Requirements Validation (ORV) sheets, DD-1494s (applications for equipment frequency allocation), and Equipment Location-Certification Information Database (ELCID). These documents were then organized into a format that could be used for analysis and then distilled to the critical parameters necessary for the feasibility assessment. The tables of the final analysis parameters for each USG assignment are located with their system results in **Appendices G and H**. The DoD team communicated with stakeholders to complete and refine the data.

[redacted]

[redacted]

6.6.2 USG Antenna Patterns

Whenever three-dimensional antenna patterns were provided for USG receivers, they were used in the analysis. In cases where only antenna parameters were given (e.g., mainbeam gain and beamwidth) a two-dimensional statistical pattern was developed utilizing the Statistical Antenna Gain (STATGAIN) algorithm based on the provided parameters. The STATGAIN algorithm is, at its core, a set of equations that determine a conservative estimate for the average sidelobe level at an off-axis angle, given a mainbeam gain as the input. STATGAIN is based on ITU/CCIR equations that predict the 90 percent sidelobe levels of large dish antennas. The sidelobe levels were determined to be approximately normally distributed, were generalized to the average/50% level and extended to other types of antennas. STATGAIN contains three sub-algorithms that apply for very-high-gain patterns (mainbeam gain ≥ 48 dBi), high-gain patterns (48dBi > mainbeam gain ≥ 22dBi), and medium-gain patterns (22dBi > mainbeam gain ≥ 9.33dBi). For low gains, below 9.33dBi, an omnidirectional pattern is used. The form for STATGAIN antenna patterns over 9.33 dBi mainbeam gain is shown in **Figure 6.14** and defined in the table shown after. Finally, **Table 6.20** illustrate how each of the three sub-algorithms calculate gains values between each of the three discontinuities.

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FIGURE 6.14: STATGAIN GENERIC ANTENNA-GAIN PATTERN.

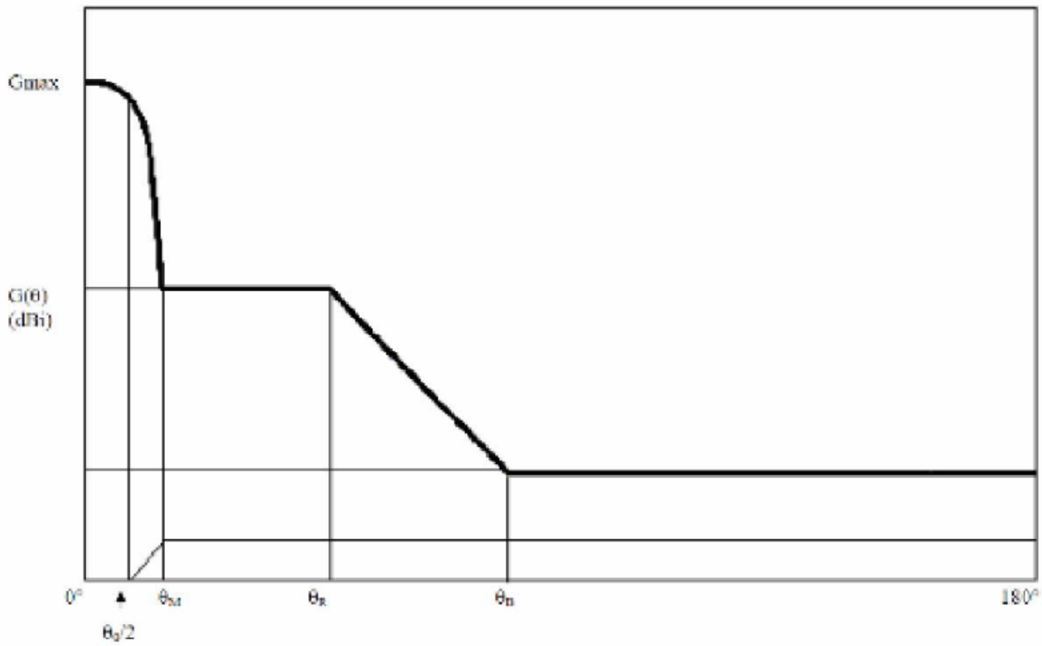

Figure 6.14: STATGAIN Generic Antenna-Gain Pattern[63]

TABLE 6.20. STATGAIN ANTENNA PATTERN EQUATIONS			
STATGAIN Model	**Discontinuity Points**	**Angular Interval, deg**	**Gain(θ), dBi**
Low Gain ($G_{MAX} < 9.33\ dBi$)	N/A - Omnidirectional	$0\ to\ 180$	G_{MAX}
Medium Gain ($9.33\ dBi \leq G_{MAX} < 22\ dBi$)	$\theta_M = 50\ (0.25\ G_{MAX} + 7)^{0.5} / 10^{G_{MAX}/20}$ $\theta_R = 27.466 * 10^{-0.3*G_{MAX}/10}$ $\theta_B = 48$	$0\ to\ \theta_M$ $\theta_M\ to\ \theta_R$ $\theta_R\ to\ \theta_B$ $\theta_B\ to\ 180$	$G_{MAX} - 4 * 10^{-4} * 10^{G_{MAX}/10} * \theta^2$ $0.75 * G_{MAX} - 7$ $53 - G_{MAX}/2 - 25\ \log\theta$ 0

[63] *See* RADCOM Engineering Theory, Appendix D – Statistical Antenna Gain (Statgain) Model, D-2.

[redacted]

TABLE 6.20. STATGAIN ANTENNA PATTERN EQUATIONS			
STATGAIN Model	**Discontinuity Points**	**Angular Interval, deg**	**Gain(θ), dBi**
High Gain ($22\ dBi \leq G_{MAX} < 48\ dBi$)	$\theta_M = 50\ (0.25\ G_{MAX} + 7)^{0.5} / 10^{G_{MAX}/20}$ $\theta_R = 250/10^{G_{MAX}/20}$ $\theta_B = 48$	$0\ to\ \theta_M$ $\theta_M\ to\ \theta_R$ $\theta_R\ to\ \theta_B$ $\theta_B\ to\ 180$	$G_{MAX} - 4 * 10^{-4} * 10^{\ G_{MAX}/10} * \theta^2$ $0.75 *\ G_{MAX} - 7$ $53 - G_{MAX}/2 - 25\ log\,\theta$ $11 - G_{MAX}/2$
Very-High Gain ($G_{MAX} \geq 48\ dBi$)	$\theta_M = 50\ (0.25\ G_{MAX} + 7)^{0.5} / 10^{G_{MAX}/20}$ $\theta_R = 250/10^{G_{MAX}/20}$ $\theta_B = 131.8257 * 10^{-G_{MAX}/50}$	$0\ to\ \theta_M$ $\theta_M\ to\ \theta_R$ $\theta_R\ to\ \theta_B$ $\theta_B\ to\ 180$	$G_{MAX} - 4 * 10^{-4} * 10^{\ G_{MAX}/10} * \theta^2$ $0.75 *\ G_{MAX} - 7$ $29 - 25\ log\,\theta$ -13

Table 6.20: STATGAIN Antenna Pattern Equations

6.6.3 USG System Radials

An important characteristic of the USG systems included in this analysis is that, barring specific restrictions, they can point in almost any azimuth angle. To properly provide protection for these systems, the model must account for the systems' ability to point in any direction within their area of operation. The term "radial" was coined to represent an analysis case for a USG system defined by a specified azimuthal pointing angle. A USG system, analyzed with multiple radials, represents the ability of the system to change azimuthal orientation. The number of radials for each USG system was determined by the following equation, where antenna beamwidth refers to the STATGAIN beamwidth. For more information on radials, refer to **Appendix B.3.3**.

$$\frac{2 * 360°}{AntennaBeamwidth(°)} = Number\ of\ Radials$$

Due to run-time increases experienced with large numbers of radials, a sensitivity analysis was performed to determine an appropriate number of radials necessary to model narrow beamwidth antennas (see Appendix B.5). It was determined that 36 radials yielded similar (nearly identical) results to 360 radials. In light of the results, 36 was used as the maximum number of radials for the analysis.

6.7 Propagation Loss

In the EMBRSS analyses, propagation loss has been partitioned into categories: losses due to wave-spreading, diffraction, atmospheric effects, clutter losses, and building penetration losses.

6.7.1 Loss due to Wave-Spreading, Diffraction, and Atmospheric Effects

The Terrain Integrated Rough Earth Model (TIREM) began in the mid-1980s as a terrestrial propagation model to compute the power loss of communication links in the 1 MHz to 1 THz range, and today has become a de-facto standard RF propagation model within the U.S. DoD. In this analysis, TIREM considers the terrain between two points on the Earth with a 2D profile representing that terrain at 10 m resolution. Based on that terrain profile, TIREM models the effects of diffraction, reflection, atmospheric absorption, and atmospheric scattering. Additional background information can be found in **Appendix B.4.1**.

6.7.2 Clutter Loss

Clutter loss is applied when a propagated signal is assumed to pass through environments with man-made or natural features, excluding terrain. ITU-R P.452[64] is used for clutter losses associated with transmitters with antenna heights greater than 6 meters above the local ground level. Recommendation ITU-R P.2108[65] is used to calculate the clutter loss for lower heights, less than 6 meters.

Consistent with standard practice, the following equation from P.452 was used to calculate clutter losses in the EMBRSS analysis for transmit antennas greater than 6 meters in height. The required parameters based on the environment of the link and the height of the interferer are summarized in **Table 6.21**. A frequency of 3450 MHz was used to calculate the clutter loss. Curves derived from the P.452 equation are displayed in **Figure 6.15** for the respective clutter categories of **Table 6.21**.

$$A_h = 10.25\, F_{fc} * e^{-d_k}(1 - tanh[6\ (h/h_a - 0.625)\ ]) - 0.33$$

where,

$$F_{fc} = 0.25 + 0.375(1 + tanh[7.5(f - 0.5)])$$

$$f\ [MHz] = Frequency$$

$$d_k\ [km] = Distance\ from\ nominal\ clutter\ point\ to\ the\ antenna$$

$$h\ [m] = Antenna\ height\ above\ local\ ground\ level$$

$$h_a\ [m] = Nominal\ clutter\ height\ above\ local\ ground\ level$$

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[64] International Telecommunication Union, Radiocommunication Sector of ITU, *Prediction procedure for the evaluation of interference between stations on the surface of the Earth at frequencies above about 0.1 GHz*, Recommendation ITU-R P.2108-1 (September 2021), https://www.itu.int/dms_pubrec/itu-r/rec/p/R-REC-P.452-17-202109-I!!PDF-E.pdf.

[65] International Telecommunication Union, Radiocommunication Sector of ITU, *Prediction of Clutter Loss*, Recommendation ITU-R P.452-17 (September 2021), https://www.itu.int/dms_pubrec/itu-r/rec/p/R-REC-P.2108-1-202109-I!!PDF-E.pdf.

TABLE. 6.21. NOMINAL CLUTTER HEIGHTS AND DISTANCES FOR CLUTTER CATEGORIES		
Clutter Category	**Nominal Clutter Height h_a (m)**	**Nominal Distance d_k (km)**
Rural	4	0.1
Suburban	9	0.025
Urban	25	0.02

Table 6.21: Nominal Clutter Heights and Distances for Clutter Categories

FIGURE 6.15: P.452 CLUTTER LOSS FOR 3450 MHZ.

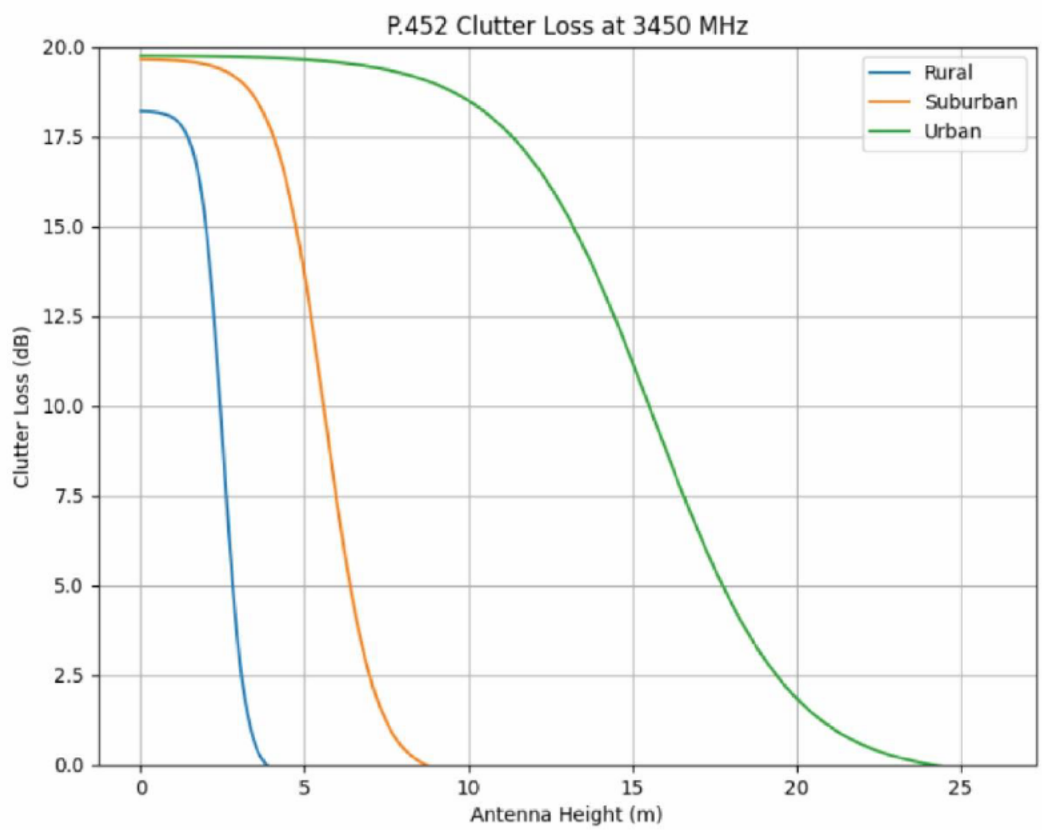

Figure 6.15: P.452 Clutter Loss for 3450 MHz

The following equation from P.2108-0 was used to calculate clutter losses in the EMBRSS analysis for transmit antennas less than 6 meters in height. The required parameters are based on the frequency, nominal distance of a link, and percentage of links to not exceed the calculated clutter loss. A frequency of 3450 MHz and a percentage of 50%, respectively, were used to calculate the clutter loss. Curves derived from the P.2108-0 equation are displayed in **Figure 6.16**.

$$L_{ctt} = -5log_{10}(10^{-0.2L_l} + 10^{-0.2L_s}) - 6Q^{-1}(p/100)$$

where,

$$Q^{-1} = Inverse\ complementary\ normal\ distribution\ function$$

$L_l = 23.5 + 9.6\ log_{10}(f)$
$L_s = 32.98 + 23.9\ log_{10}(d) + 3\ log_{10}(f)$
$f\ [MHz] = Frequency$

FIGURE 6.16: P.2108-0 MEDIAN CLUTTER LOSS.

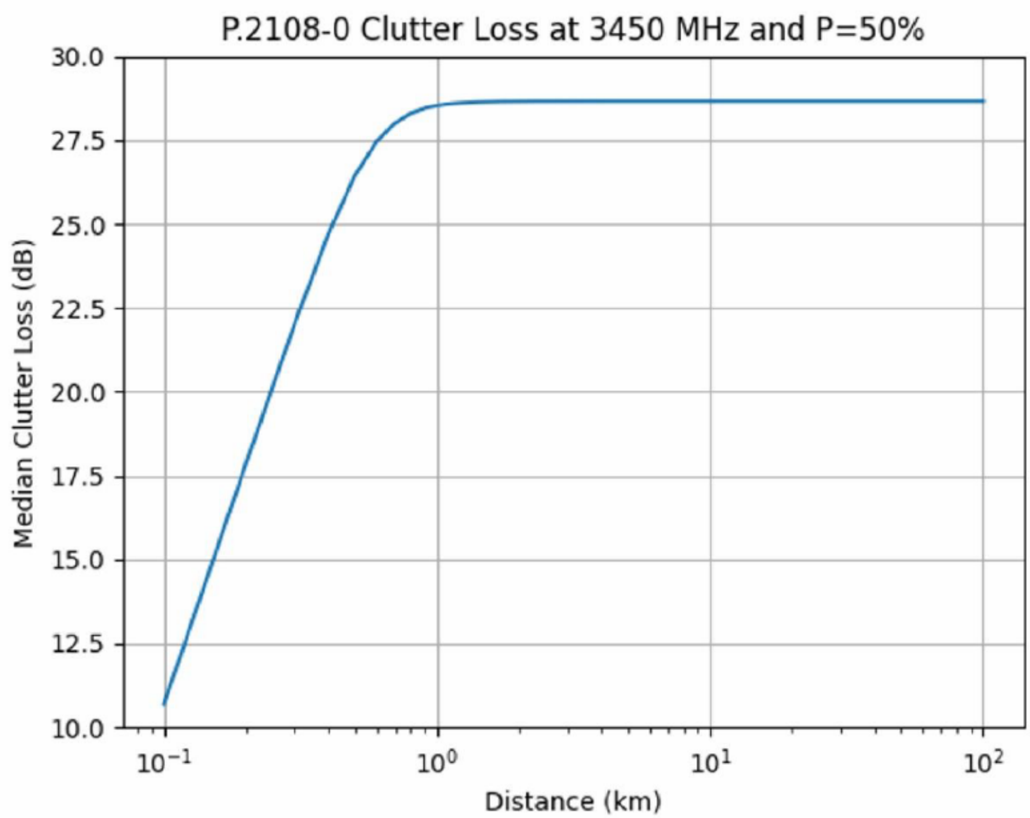

Figure 6.16: P.2108-0 Median Clutter Loss for 3450 MHz

Table 6.22 provides the clutter model and clutter loss value used for each of the transmitter cell types, environments, and heights used in the EMBRSS analyses.

TABLE 6.22. CLUTTER LOSS CONSIDERATIONS FOR 3450 MHz

Cell Type	Environment	Antenna Height (m)	Model	Clutter Loss (dB)
Macro	Urban	20m	P.452	1.86
Macro	Suburban	25m	P.452	0
Macro	Rural/FCC Rural	35m	P.452	0
Micro Indoor	Urban	20m	P.452	1.86
		15m	P.452	11.21
		10m	P.452	18.50
		5m	P.2108-0	28.35
Indoor	Suburban	20m	P.452	0
		15m	P.452	0
		10m	P.452	0
		5m	P.2108-0	28.35
Indoor	Rural/FCC Rural	20m	P.452	0
		15m	P.452	0
		10m	P.452	0
		5m	P.2108-0	28.35
Outdoor	All	6m	P.2108-0	28.35

Table 6.22: Clutter Loss Considerations for 3450 MHz

6.7.3 Building Penetration Loss

Building penetration loss is the amount of attenuation of a signal as it passes from inside a structure to the outside world. For indoor transmitters, recommendation ITU-R P.2109-1 provides a method for estimating building entry loss. Based on the two types of buildings modeled in this recommendation, the average ITU P.2109 equivalent factors considered were

[redacted]

traditional (-12.17dB) and thermally efficient (-23.68 dB).[66] Considering these results and wireless telecommunications industry input, a 15dB building penetration loss was used throughout the analysis for commercial systems operating indoors.

6.8 Frequency Dependent Rejection

The amount of rejection that a receiver provides to a particular undesired signal, typically given in dB, is referred to as the Frequency Dependent Rejection (FDR). FDR is a key component of the link budget described in **Section 6.5**. Calculating FDR involves using methods defined in ITU-R SM.337-6.[67] The following are needed to calculate the FDR for each link: an emission PSD curve, receiver selectivity curve, and the frequency separation from the emission center frequency to the receiver center frequency.

6.8.1 Emission PSD Curves

In **Appendix B.5.1**, there is a description of all 18 possible emission PSD curves for the various 5G base stations and the method used to develop those PSD curves. Each of the emission curves will be used to calculate 18 FDR values for a given receiver. **Figure 6.17** shows an example of a normalized emission curve for a macrocell base station.

[66] International Telecommunication Union, Radiocommunication Sector of ITU, *Prediction of Building Entry Loss*, Recommendation ITU-R P.2109-1 (August 2021), https://www.itu.int/dms_pubrec/itu-r/rec/p/R-REC-P.2109-1-201908-I!!PDF-E.pdf.

[67] *See* International Telecommunication Union, Radiocommunication Sector of ITU, *Frequency and Distance Separations*, Recommendation ITU-R SM.337-6, (October 2008), https://extranet.itu.int/brdocsearch/R-REC/R-REC-SM/R-REC-SM.337/R-REC-SM.337-6-200810-I/R-REC-SM.337-6-200810-I!!PDF-E.pdf.

[redacted]

[redacted]

FIGURE 6.17: NORMALIZED EMISSION PSD CURVE FOR MACROCELL 5.

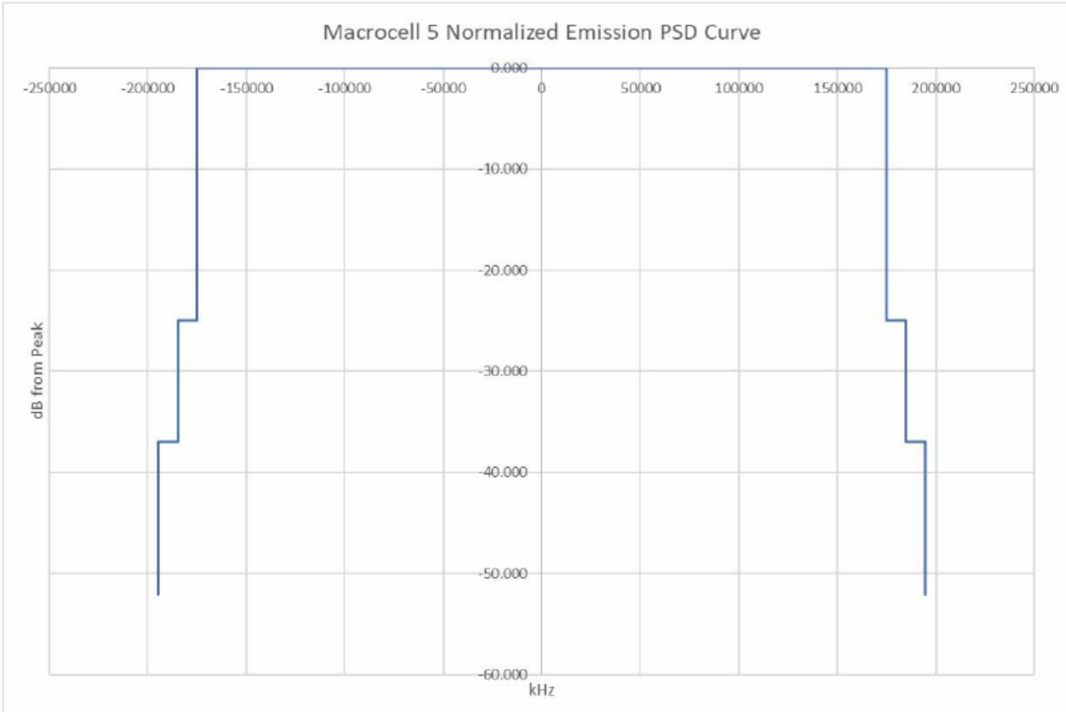

Figure 6.17: Normalized Emission PSD Curve for Macrocell

In **Figure 6.17**, the plot ends at $\pm$195 kHz. Although not shown, the plot extends toward $\pm\infty$ by use of an "extrapolation slope." For all the 18 5G curves modeled, the extrapolation slope chosen was 20 dB/decade applied from the last point on the emission spectra. This emission mask does not account for the frequency response of the antenna.

6.8.2 Receiver Selectivity Curves

The receiver selectivity curve is a measure of the amount of attenuation the receiver provides to a signal as a function of frequency. If a receiver has multiple filtering stages, then the stage with the narrowest bandwidth selectivity was chosen. Of note, increasingly a "wideband" or "medium-band" mode is deployed to fulfil certain mission requirements. **Figure 6.18** shows an example selectivity curve, centered at 0 Hz.

[redacted]

FIGURE 6.18: RECEIVER SELECTIVITY CURVE EXAMPLE.

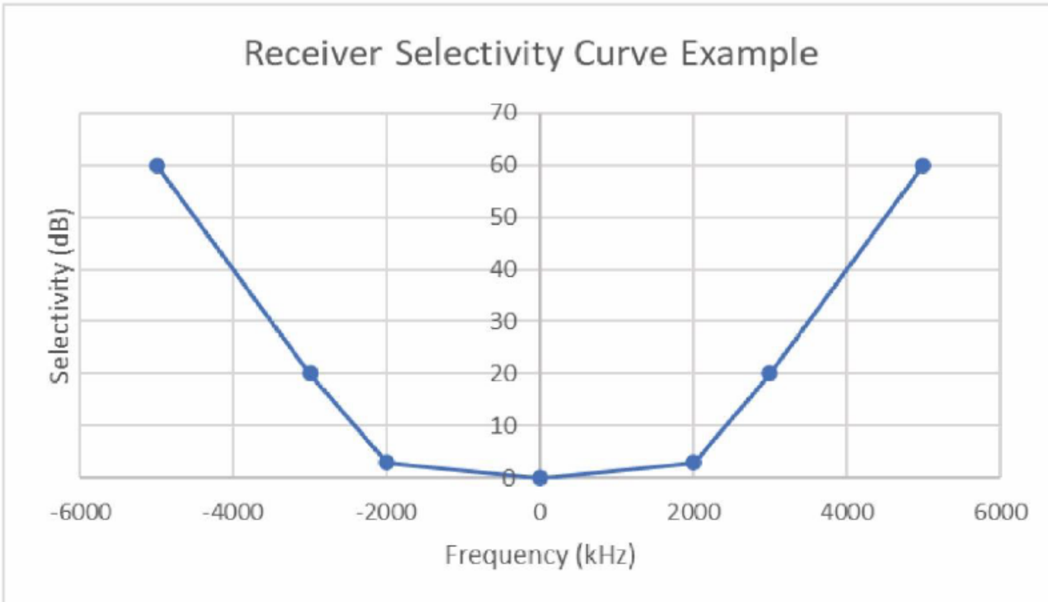

Figure 6.18: Receiver Selectivity Curve Example

In **Figure 6.18**, the plot ends at ±5000 kHz. In the same way as for the emission PSD curves, an extrapolation slope is used beyond the extent of the receiver selectivity curve. For each USG system receiver modeled, the extrapolation slope chosen was 40 dB/decade.

6.8.3 Frequency Separation

The frequency separation is defined as the difference between the tuned frequency of the transmitter and the tuned frequency of the receiver. Based on the tuning range and bandwidth of the receiver, a receiver tuned frequency was determined and compared with the EMBRSS center frequency to find the frequency separation for each receiver assignment. A detailed description of determining the frequency separation is provided in **Appendix B.5.3**.

6.8.4 Interference Power Scaling

Assessing the impact from a 5G network to a specific USG system at a specific geographical location requires knowledge of the USG system location within the EMBRSS frequency band and the 5G license structure in the vicinity of the USG system. A generalized analysis that provides an assessment of a USG system type—independent of its location in the band and the nearby 5G license structure—[redacted]

For example, consider a USG system with a 3 dB selectivity curve BW of 15 MHz situated within a 5G deployment that is expected to generate, at the input to the USG receiver, -10 dBm of aggregate interference power in a 10 MHz band. [redacted]

6.9 Interference Protection Criteria Calculation

An Interference Protection Criteria (IPC) provides a measure of the interference a receiver can tolerate before an unacceptable degradation in receiver performance occurs. All USG system IPCs were given in terms of interference to noise ratio (I/N). Therefore, if the ratio of interference power in the receiver to the receiver's noise power exceeds the I/N threshold provided, then harmful interference is predicted. An I/N value of -6 dB was assumed for all systems unless otherwise stated. Explicitly, to determine when an emitter interferes with a receiver:

interference occurs when,

$$(I/N)_{calculated}\,[dB] \;>\; (I/N)_{threshold}\,[dB]$$

interference does not occur when,

$$(I/N)_{calculated}[dB] \leq\; (I/N)_{threshold}\,[dB]$$

$(I/N)_{calculated}$ can be determined by calculating the interference power I, the receiver noise power N, and then taking the ratio of the two.

$$(I/N)_{calculated}\,[dB] \;= I\,[dBm] - N[dBm]$$

The interference power I for each 5G emitter modeled is determined through the link budget described in **Section 6.5**. The noise power is a function of the receiver's 3 dB IF bandwidth and Noise Figure (NF), shown in the below equation. These values for each receiver were gathered in the data collection process described in **Section 6.7.1**.

$$N\,[dBm] = -174\;dBm/Hz +\; 10\log_{10}\big(Receiver3dBBandwidth[Hz]/(1Hz)\big) + NF[dB]$$

6.9.1 IPC Apportionment for Partial Band Overlap

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

6.10 Interference Aggregation

Aggregate interference to the radar systems analyzed were modeled throughout this analysis. Aggregate interference is computed from individual contributions made by each 5G transmitter at the USG radar after application of link budget inputs.

The aggregate interference was calculated by converting each received power level into watts, adding the received power at the radar receiver from each 5G macro/microcell transmitter within the simulation area, and then converting the aggregate power received back to dBm. 5G signals were considered to behave as Additive White Gaussian Noise (AWGN) from the perspective of the receiver because the signals are assumed to be non-coherent. Therefore, aggregate 5G signals can be treated as additive. To accomplish this, the aggregate interference was calculated using the below formulas:

Step 1:

$$P_{R_{mW}} = 10^{\left(\frac{P_{R_{dBm}}}{10}\right)}$$

Step 2:

[redacted]

$$P_{R_{mW_{aggregate}}} = \sum_{k=1}^{n} P_{R_{mW_k}}$$

Step 3:

$$P_{R_{dBm_{aggregate}}} = 10\ log_{10}\left(P_{R_{mW_{aggregate}}}\right)$$

where,

$P_{R_{mW}}$ = received power at the receiver in mW
$P_{R_{mW_{aggregate}}}$ = aggregate power at the receiver in mW
$P_{R_{dBm_{aggregate}}}$ = aggregate power at the receiver in dBm

Adding two linearly polarized plane electromagnetic waves with equal wavelengths but different phases, traveling along the x-axis.

$$E1(x,t) = A1\ exp(i(kx - \omega t + \varphi 1)), \qquad E2(x,t) = A2\ exp(i(kx - \omega t + \varphi 2)),$$
$$E(x,t) = E1(x,t) + E2(x,t) = (A1\ exp(i\varphi 1) + A2\ exp(i\varphi 2))\ exp(i(kx - \omega t))$$
$$= AR\ exp(i(kx - \omega t + \varphi R)).$$

The result of the addition is a linearly polarized plane electromagnetic waves with the same wavelength but a different phase and amplitude, traveling along the x-axis.

AR is the resultant amplitude and φR is the resultant phase.

$$\text{A1}\exp(i\varphi 1) + \text{A2}\exp(i\varphi 2) = \text{AR}\exp(i\varphi \text{R})$$

To find the magnitude of a complex number we multiply the number by its complex conjugate and then take the square root.

$$AR2 = (A1\exp(i\varphi 1) + A2\exp(i\varphi 2))(A1\exp(-i\varphi 1) + A2\exp(-i\varphi 2))$$
$$= A12 + A22 + A1A2(exp(i(\varphi 1 - \varphi 2)) + exp(-i(\varphi 1 - \varphi 2)))$$
$$= A12 + A22 + 2A1A2cos(\varphi\ 1 - \varphi 2).$$

To add two non-coherent signals, assume the waves have a 90° phase shift. φ 1- φ2 =90.

$$AR2 = A12 + A22 + 2A1A2cos(\varphi\ 1 - \varphi 2).$$
$$Cos(90°) = 0, Cos(270°) = 0$$
$$AR2 = A12 + A22$$
$$A_R = \sqrt{A_1^2 + A_2^2}$$
$$If\ A1 = 1, \qquad A2 = 1, \qquad AR = 1.41$$
$$\sqrt{(1^2 + 1^2)} = 1.41$$

If we add two voltages (non-coherently), we get a 3dB increase in Power.

6.11 Culling Algorithms

[redacted]

6.11.1 Nearest Neighbor

As a baseline analysis approach, a “nearest neighbor” algorithm was implemented to determine the geographic separation distance at which interferers would need to turn off. This approach takes the closest interferer and removes it from the aggregate interference calculation, effectively “turning it off” or removing it from consideration. The algorithm then recalculates the aggregate interference and turns off the next closest interferer. It repeats these two steps until it reaches a point at which the maximum aggregate received power at any one of the radar’s pointing angles is below the IPC threshold. The distance to the last turned-off base station is the geographic separation distance, within which all interferers are turned off.

The nearest neighbor algorithm provides a straightforward view of the effect of aggregate interference on the receiver and has been used in the past to simplify coordination activities. Alternative culling algorithms can be used to emphasize other aspects of the analysis but are often more complex. For example, a culling algorithm, described further in **Section 6.11.2**, iteratively turns off the worst-case interferer rather than the closest interferer. This power culling algorithm will provide irregular shapes of turned-off interferers, significantly dependent on terrain, which makes interpretation and coordination more complex. Therefore, the nearest neighbor algorithm was chosen for its simplicity for the baseline analysis.

6.11.2 Received Power Contribution

Rather than sorting the interferers by distance, this algorithm sorts the interferers based on the largest interference contribution to the radar receiver. The algorithm starts by selecting the radar pointing angle with the highest aggregate received power. It then finds the interferer with the maximum interference contribution as it applies to the selected radar pointing angle. The algorithm then turns this interferer off and removes it from the calculations for all the radar pointing angles. The algorithm repeats this step and recalculates the received aggregate power at each radar pointing angle, again determining the maximum interferer, and turning it off for all radar pointing angles. The algorithm continues this process until the aggregate received power at each pointing angle is below the system interference threshold.

6.12 Baseline Analysis

6.12.1 Baseline Modeling Objective

A baseline analysis was performed for each USG radar, at each unique operating location. The objective of the analysis is to establish a baseline from which to compare the COA analysis results against and to quantify their benefit. For comparison, the baseline analysis defines the required geographic separation distance between USG radars and 5G base stations to ensure no harmful interference is experienced by the radar.

6.12.2 Baseline Modeling Assumptions

Multiple assumptions were made in the setup and execution of the baseline analysis. They are summarized below:

1. One-way analysis modeling interference from 5G transmitters into USG radar receivers.

2. No coordination between users.

3. The only information that is known to 5G operators is the latitude/longitude and/or area of operation of a given radar, the tuning range of the radar, and the radar's geographic separation distance requirement.

4. No base stations are permitted to operate (full power down) within the separation distance radius.

5. Base stations beyond the geographic separation distance are assumed to be operating normally (i.e., at full power).

[redacted]

6.12.3 Baseline Modeling Steps

The steps taken to perform the baseline analysis are summarized below, with references to the above sections that elaborate on the specific details.

1. Model radar receiver per the system specifications in **Appendix B.9.3** at the authorized assignment location for a fixed system, along the perimeter of the area of operation for a mobile system, along the coast for a shipborne system, or along a flight path for an airborne system.

2. Set the discrete antenna pointing angles to simulate a radar sweep.

3. Model 5G deployment within analysis area radius for the radar system of interest in the location of the analysis.

4. Calculate received power at the radar for individual links (see link budget).

5. Aggregate total received power at each radar pointing angle (radial).

6. Turn off base stations within the area of operation (if applicable).

7. Compare the initial aggregate received power to the interference threshold (Receiver Noise Level + IPC). If the aggregate power exceeds the interference threshold, implement the nearest neighbor culling algorithm until the aggregate received power at each pointing angle is below the interference threshold.

8. Define the Geographic Separation Distance as the distance from the radar to the furthest base station that is turned off.

9. Plot the results.

6.12.4 Baseline Result Graphics

As an introduction to the graphical representation of the baseline analysis results, this section will describe the layout of the output plots. Understanding the output plots correctly is crucial to the interpretation of the results. The graphical maps produced to show the geographic separation required to enable coexistence between a 5G network and the USG system. The plot, shown in **Figure 6.19** depicts the USG system – in this example a mobile system modeled by five receiver locations, called probe points, are placed on the perimeter of the area of operation, and the 5G network surrounding it. Macrocell base stations are depicted by a square icon and microcell base stations are depicted as circles. The blue circle plots the baseline geographic separation distance as measured from the edge of the radar's area of operation. Red base stations indicate they are required to turn off the frequencies occupied by the radar as it is located within the geographic separation distance, while the green base stations are permitted to continue normal operations.

[redacted]

As assumptions about the 5G deployment change, the geographic separation distance will need to be recalculated. The baseline analysis produces a result for each 5G deployment power scenario analyzed. The results are largely dependent upon the density of the 5G deployment in the specific locations analyzed as well as the terrain features within the analysis area. Each unique location for each radar in the 3100-3450 MHz band was analyzed and the baseline results can be visualized from a high level to understand the total geographic impact of the system across CONUS. This view is shown for a single radar system in **Figure 6.20** below.

[redacted]

The CONUS geographic impact graphic above, in **Figure 6.20**, shows locations of this particular USG system as red stars with a light blue circle representing the area of operation at each location. The dashed circles represent the geographic separation distance for the High Power case calculated by the analysis at that location. Similar dashed circles for the mid and low power cases would be smaller and exclude less area from commercial operations. Each USG system will have a corresponding "layer" of the results of each 5G deployment power scenario. These layers can then be aggregated to overlay the geographic impact of multiple USG radars on a given area. USG radar locations depicted here may change based on deployment considerations and contractor requirements in support of development and sustainment contracts.

6.13 COA Model Development

The spectrum sharing approaches analyzed in this feasibility assessment, known as the spectrum sharing COAs, were introduced in **Chapter 3**. These COAs include interference mitigation and/or coordination features that were proposed and agreed upon in the PATHSS working group.

6.13.1 COA Modeling Objective

The objective of the COA analyses is to quantify each COAs' ability to improve spectrum sharing opportunities between USG and 5G systems in the band.

6.13.2 COA Analysis Approach

The baseline analysis described throughout **Chapter 6** provides insight into the required geographical separation between USG and 5G systems to allow for them to share spectrum in the EMBRSS band (3100 - 3450 MHz), assuming that no interference mitigation techniques are employed.

Two COAs proposed by the PATHSS TG were modeled, COA 1: Active 5G RAN, which focuses on features expected to be available to 5G RAN that may reduce interference to USG systems if applied; and COA 2: Dynamic Spectrum Management System (DSMS), which considers a centralized system for coordination between Federal and non-Federal users to automate the coordination necessary to enable spectrum sharing. A combination of the two COAs was also analyzed to determine if the benefits were additive when combined. Each COA and interference mitigation feature is first analyzed independently, against the high, mid, and low-power scenarios. The COAs, deployment models, and interference mitigation features analyzed are summarized in **Table 6.23.**

TABLE 6.23. SPECTRUM-SHARING COA CONFIGURATION ANALYZED

COA	Deployment Scenario	Interference Mitigation Feature
Active 5G RAN	High/Mid/Low-Power Scenarios	Physical Resource Block (PRB) Blanking
		Antenna Beam Muting
		Antenna Null Steering
DSMS	High/Mid/Low-Power Scenarios	gNB move in frequency, power down, or turn off (Turn Off)
DSMS + Active 5G RAN	High/Mid/Low-Power Scenarios	Physical Resource Block (PRB) Blanking + limited Turn Off
		Antenna Beam Muting + limited Turn Off
		Antenna Null Steering + limited Turn Off

Table 6.23: Spectrum-Sharing COA Configuration Analyzed

To see how COAs improve spectrum sharing in EMBRSS, the link budget from the baseline analysis was modified, and the aggregate interference levels were recalculated. These are assuming a specific COA is implemented at capable 5G base stations, whose operations are within the analysis area of a US Government system (USGS). **Figure 6.21** describes the analysis approach workflow.

FIGURE 6.21: EXAMPLE CONUS GEOGRAPHIC IMPACT FOR A USG RADAR.

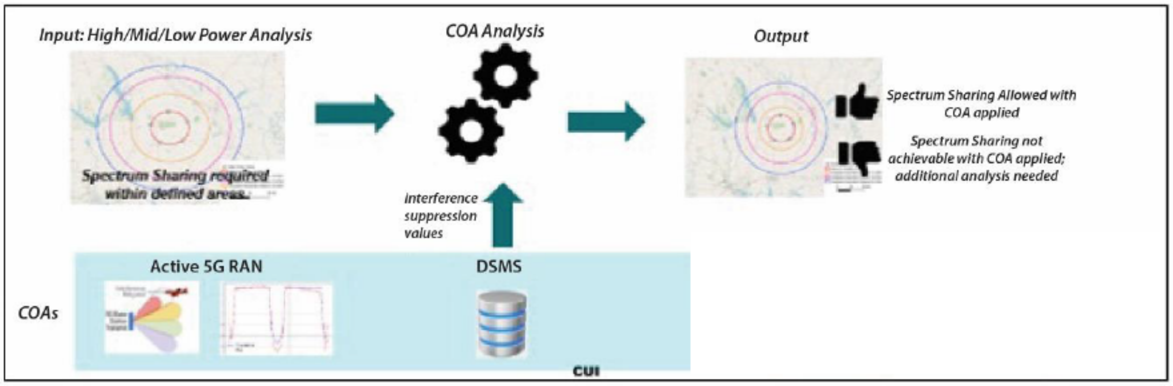

Figure 6.21: COA Analysis Approach Workflow

6.13.3 COA 1: Active 5G RAN

6.13.3.1 COA 1 Modeling Approach – Interference Mitigations

The Active 5G RAN COA includes integrated radar waveform detection, PRB Blanking, Beam Muting, and Null Steering. The first feature, integrated radar waveform detection, will be used to determine when one of the other three features is needed to reduce interference power to USG systems. A determination of the amount of interference suppression achievable for each technique is based on analysis, measurements, and subject matter experts' expectations for each approach, as available. The associated interference suppression value is then inserted into the link budget equation, as a reduction, to assess the spectrum-sharing improvements for the technique. This reduction was applied to appropriate base stations within the COA 1 activation distance. This distance seeks to maximize the benefit of the interference mitigation while minimizing the number of base stations required to implement the COA 1 interference mitigation. Using the new aggregate interference power values, the required separation distance is then recalculated to determine the spectrum-sharing benefit of the technique.

For COA 1, the following interference mitigation features were analyzed: Physical Resource Block (PRB) Blanking, Beam Muting, and Null Steering. A PRB exists in two dimensions: time and frequency. PRB blanking enforces a restriction on 5G systems to not use frequencies the USG receiver is monitoring (see **Figure 6.22**). This interference mitigation technique can be implemented by both macro and microcells. Based on industry input and a research review, an interference suppression value of 25 dB[68] was included in the link budget as a reduction in interference power to account for PRB blanking in macrocell and microcell base stations.

[68] See **Appendix C:** Additional Information on Null Steering & Beam Muting.

FIGURE 6.22: COA ANALYSIS APPROACH.

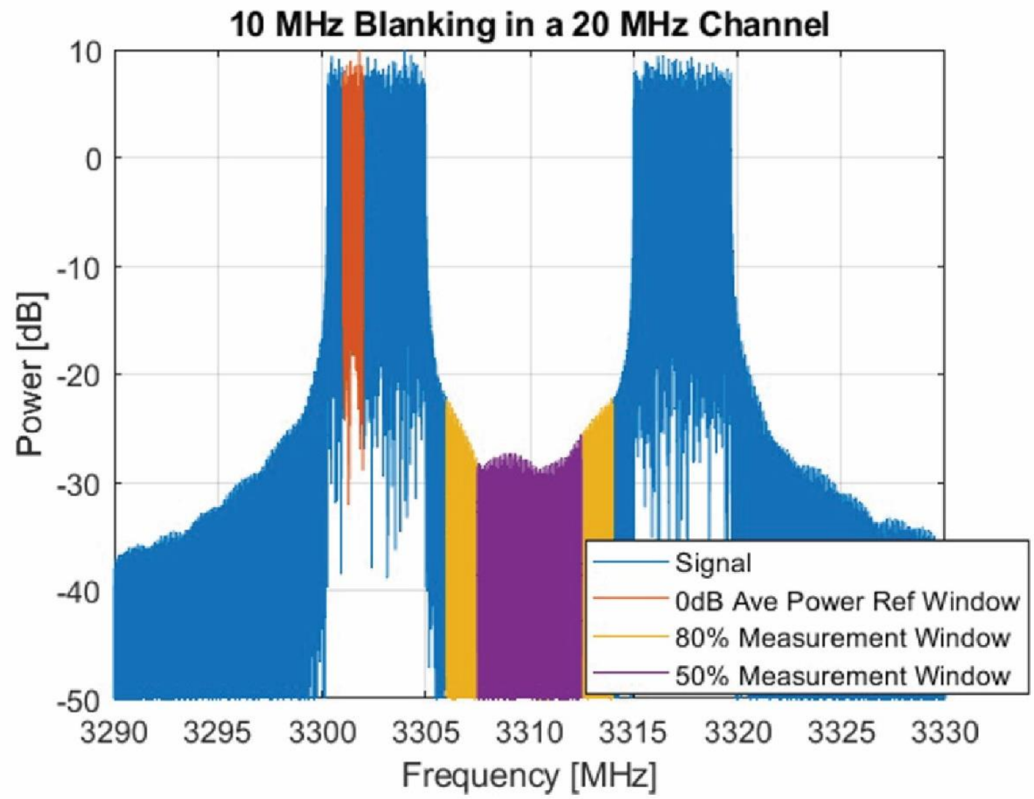

Figure 6.22: Effects of PRB Blanking in the Frequency Domain

Beam muting, shown in **Figure 6.23**, is a feature built into the 5G Advanced Antenna System (AAS) that restricts the 5G systems' use of one or more antenna patterns available for use when targeting specific UEs in a sector. Antenna patterns that maximize gain in the direction of an operating USG system are not allowed thereby reducing the interference power. Other antenna patterns are used to service UEs in the same direction as the USG system, though at lower power levels. Because only macrocells are modeled with an AAS antenna, the beam muting interference mitigation is only applied to macrocells in the analysis. Based on DoD modeling and an academic journal review, an interference suppression value of 10 dB[69] was included in the link budget as an additional loss to account for beam muting in macrocell base stations only.

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[69] Siva Lakshmanan et al., "Effectiveness of 5G Cellular Interference Mitigation Techniques for Airborne Radar Spectrum Coexistence in the 3.1 – 3.45 GHz Band" (Military Communications Conference, November 29, 2022).

[redacted]

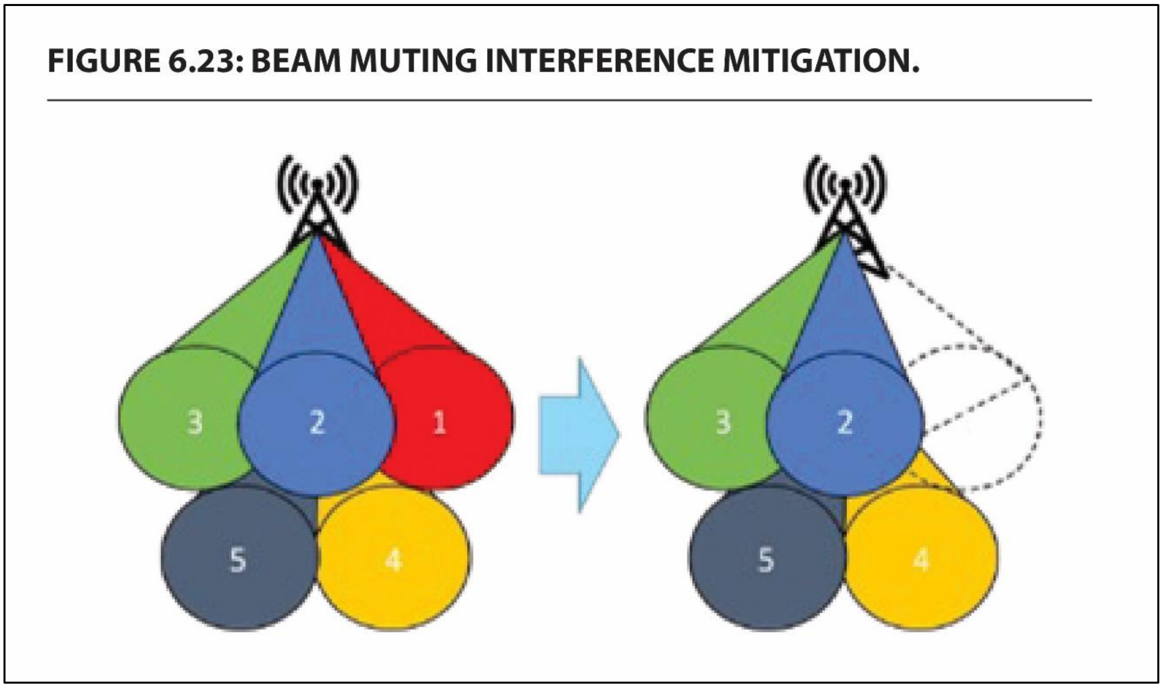

Figure 6.23: Beam Muting Interference Mitigation

Null steering is similar to beam muting but goes further by using a custom antenna pattern that places a null in the direction of the USG system. The AAS is an electronically steered array which is used to steer the beams in the direction of the user equipment that is being served by the base station. In null steering algorithms, the weights of an antenna array are selected such that the directional pattern has nulls in particular directions to mitigate interference. Because only macrocells are modeled with an AAS antenna, the null steering interference mitigation is only applied to macrocells in the analysis. An example antenna pattern showing a steered null is shown in **Figure 6.24**.

[redacted]

[redacted]

FIGURE 6.24: AAS ANTENNA PATTERNS SHOWING NULL STEERING EFFECTS.

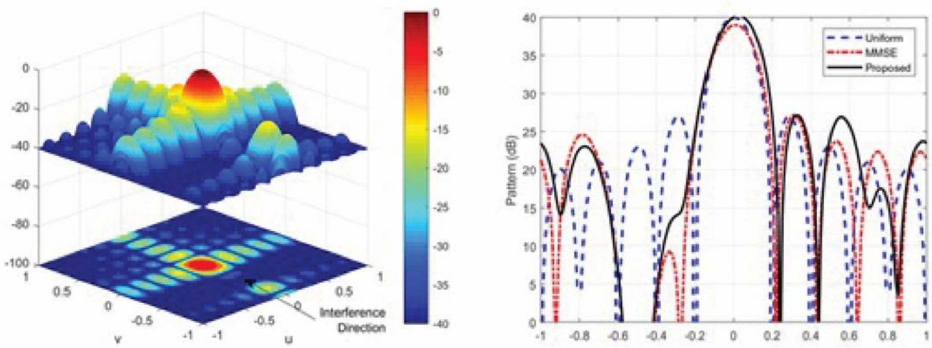

Figure 6.24: Example of AAS Antenna Patterns Showing Null Steering Effects

Based on industry input and an academic journal review, an interference suppression value of 30 dB[70] was included in the link budget as an additional loss to account for null steering in macrocell base stations only.

6.13.3.2 COA 1 Modeling Assumptions

Multiple assumptions were made in the setup and execution of the COA 1 analysis and are summarized below:

1. The 5G base station is aware of the impacted radar's location, occupied frequencies, separation distance at which interference mitigation is required, and separation distance at which the occupied frequencies must be turn off. (COA 1)

2. All capable base stations within the activation distance are implementing the interference mitigation technique under investigation. (COA 1)

3. PRB-Blanking is not feasible as an interference mitigation technique for radars with receive bandwidths over 50 MHz, or for radars who employ frequency hopping.

4. Implements the nearest neighbor culling algorithm, turning off base stations (full power down) until the aggregate received power at each pointing angle is below the interference threshold. (COA 1)

5. The geographic separation distance is defined as the distance from the radar to the furthest base station that is required to turn off.

[70] NTIA, *Spectrum Compendium: 3100-3300 MHz* (December 2015).

[redacted]

6. 1-way analysis modeling interference from 5G transmitters into USG radar receivers.

[redacted]

6.13.3.3 COA 1 Link Budget Summary

Link budget summaries are shown in **Tables 6.24-6.26** below for the three interference mitigation techniques modeled for COA 1: Active 5G RAN with the differentiators highlighted.

TABLE 6.24. COA 1: PRB BLANKING LINK BUDGET SUMMARY					
Variable		**Macro**	**Outdoor Micro**	**Indoor Micro**	**Radar**
EIRP (dBm)	Urban/Suburban/Rural	72/58/47	29	24	
	FCC Rural	75/61/47			
Ant. Height (m)	Urban	20	6	(5,10,15,20, etc.)	
	Suburban	25			
	Rural	35			
PRB Blanking (dB)		-25	-25	-25	0
Ant. Pattern		3 Sector AAS	Omni	Omni	
Clutter Loss		P.452	P.2108	P.452 or P.2108	
Network Loading (dB)		-5.23 (30%)			
TDD Factor (dB)		-1.25 (75% DL)			
Propagation Loss		TIREM 6			
FDR			MSAM		
Polarization Mismatch Loss (dB)			[redacted]		

TABLE 6.24. COA 1: PRB BLANKING LINK BUDGET SUMMARY				
Variable	**Macro**	**Outdoor Micro**	**Indoor Micro**	**Radar**
Ant. Pattern		Measured or STATGAIN		
Ant. Height		ORV Supplied		
Culling Method	Nearest Neighbor culling algorithm			

Table 6.24: COA 1: PRB Blanking Link Budget Summary

TABLE 6.25. COA 1: BEAM MUTING LINK BUDGET SUMMARY

Variable		Macro	Outdoor Micro	Indoor Micro	Radar
EIRP (dBm)	Urban/Suburban/Rural	72/58/47	29	24	
	FCC Rural	75/61/47			
Ant. Height (m)	Urban	20	6	(5,10,15,20, etc.)	
	Suburban	25			
	Rural	35			
Beam Muting (dB)		-10	0	0	0
Ant. Pattern		3 Sector AAS	Omni	Omni	
Clutter Loss		P.452	P.2108	P.452 or P.2108	
Network Loading (dB)		-5.23 (30%)			
TDD Factor (dB)		-1.25 (75% DL)			
Propagation Loss		TIREM 6			
FDR					MSAM
Polarization Mismatch Loss (dB)					[redacted]
Ant. Pattern					Measured or STATGAIN
Ant. Height					ORV Supplied
Culling Method		Nearest Neighbor			

Table 6.25: COA 1: Beam Muting Link Budget Summary

TABLE 6.26. COA 1: NULL STEERING LINK BUDGET SUMMARY					
Variable		**Macro**	**Outdoor Micro**	**Indoor Micro**	**Radar**
EIRP (dBm)	Urban/Suburban/Rural	72/58/47	29	24	
	FCC Rural	75/61/47			
Ant. Height (m)	Urban	20	6	(5,10,15,20, etc.)	
	Suburban	25			
	Rural	35			
Null Steering (dB)		-30	0	0	
Ant. Pattern		3 Sector AAS	Omni	Omni	
Clutter Loss		P.452	P.2108	P.452 or P.2108	
Network Loading (dB)		-5.23 (30%)			
TDD Factor (dB)		-1.25 (75% DL)			
Propagation Loss		TIREM 6			
FDR					MSAM
Polarization Mismatch Loss (dB)					[redacted]
Ant. Pattern					Measured or STATGAIN
Ant. Height					ORV Supplied
Culling Method		Nearest Neighbor			

Table 6.26: COA 1: Null Steering Link Budget Summary

6.13.3.4 COA 1 Result Graphics

COA 1 results plots, shown in **Figure 6.25** below, build upon the concepts from the baseline results graphics and again show the baseline separation distance for comparison. These represent a snapshot in time and would change as the locations of the radar or the 5G devices change. The re-calculated geographic separation distance for COA 1 is also shown on the map. The yellow squares and circles are base stations that have implemented the interference mitigation technique, and the red squares and circles are base stations that must turn off the occupied frequencies to avoid causing harmful interference. The green circles and squares are beyond the edge of the analysis area and are assumed to be maintaining normal operations.

[redacted]

The COA 1: Beam Muting (**Figure 6.26**) and Null Steering (**Figure 6.27**) graphics below looks very similar to the PRB blanking result, but since these interference mitigations are only enabled on macrocells, there are green microcells operating normally intermixed with the yellow macrocells that have implemented the mitigation technique.

[redacted]

[redacted]

[redacted]

[redacted]

6.13.4 COA 2: Dynamic Spectrum Management System (DSMS)

6.13.4.1 COA 2 Modeling Approach

Based on the PATHSS TG discussion, COA 2 (DSMS) is envisioned to be a centralized system for coordination between Federal and non-Federal users, similar to the Spectrum Access System (SAS) in the CBRS band or the Automated Frequency Coordination (AFC) system deployed in 6 GHz. This system would establish protected channels for incumbents to support time, area, and spectrum decisions leveraging clear communication of temporal USG radar use.

In the COA 2 analysis, it is assumed that the DSMS has perfect information about the electromagnetic environment, the RF characteristics of the systems in the band, the operational configuration, and time domain usage information at its disposal to manage spectrum access. This allows the DSMS to implement a variety of algorithms that can optimize on any element within the dataset. In the COA 2 analysis, the algorithm selected implements the received power culling method, which seeks to minimize the number of base stations required to turn off the occupied frequencies. This algorithm is similar, if not identical, to the optimization that is done when evaluating Coordination Requests in other shared bands such as AWS-3 or AMBIT. Alternative culling algorithms may also improve spectrum sharing and can be implemented beyond this feasibility analysis.

All other elements of the link budget are identical to the baseline analysis approach, where base stations are either operating normally or required to turn off (green/red). In light of the temporal usage information envisioned to be contained in the DSMS, when the USG radar is not operating, all 5G base stations may resume normal operations.

6.13.4.2 COA 2 Modeling Assumptions

Multiple assumptions were made in the setup and execution of the COA 2 analysis and are summarized below:

1. The DSMS has perfect information (all information available to the model) about the RF characteristics of the systems in the band, the operational configuration, and time domain usage information at its disposal to manage spectrum access while ensuring no harmful interference to USG radars. (COA 2)

2. The DSMS has the authority to exert command and control over the 5G base stations. (COA 2)

3. The DSMS implements the received power culling algorithm, turning off base stations (full power down) until the aggregate received power at each pointing angle is below the interference threshold. (COA 2)

4. Base stations that are not turned off are permitted to operate normally. (COA 2)

5. 1-way analysis modeling interference from 5G transmitters into USG radar receivers.

- [redacted]
- [redacted]
- [redacted]

6.13.4.3 COA 2 Link Budget Summary

The link budget summary is shown in **Table 6.27** below for the COA 2: DSMS analysis, with the differentiator highlighted.

TABLE 6.27. COA 2: DSMS LINK BUDGET SUMMARY

Variable		**Macro**	**Outdoor Micro**	**Indoor Micro**	**Radar**
EIRP (dBm)	Urban/Suburban/ Rural	72/58/47	29	24	
	FCC Rural	75/61/47			
Ant. Height (m)	Urban	20	6	(5,10,15,20, etc.)	
	Suburban	25			
	Rural	35			
Ant. Pattern		3 Sector AAS	Omni	Omni	
Clutter Loss		P.452	P.2108	P.452 or P.2108	
Network Loading (dB)		-5.23 (30%)			
TDD Factor (dB)		-1.25 (75% DL)			
Propagation Loss		TIREM 6			
FDR					MSAM
Polarization Mismatch Loss (dB)					[redacted]

TABLE 6.27. COA 2: DSMS LINK BUDGET SUMMARY				
Variable	**Macro**	**Outdoor Micro**	**Indoor Micro**	**Radar**
Ant. Pattern				Measured or STATGAIN
Ant. Height				ORV Supplied
Culling Method	Received Power Contribution			

Table 6.27: COA 2: DSMS Link Budget Summary

6.13.4.4 COA 2 Result Graphics

COA 2 results plots, shown in **Figure 6.28** below, build upon the concepts and depictions from the baseline and COA 1 results graphics by again showing the baseline separation distance for comparison. Because the DSMS has all the information needed to optimize the spectrum sharing solution for a given scenario/environment, the minimum number of base stations are required to turn off the occupied frequencies to enable co-existence. The red squares and circles are base stations that must turn off the occupied frequencies to avoid causing harmful interference in the aggregate to the USG radar. These represent a snapshot in time and would change as the locations of the radar or the 5G devices change. The green circles and squares are permitted to maintain normal operations. In most cases, the furthest interferer (displayed as a red explosion icon) is beyond the baseline geographic separation distance, but by turning it off, it allows many base stations within the baseline distance to remain on.

[redacted]

6.13.5 COA 1 + COA 2: Active 5G RAN + DSMS

6.13.5.1 COA 1 + COA 2 Modeling Approach

In the COA 1 + COA 2 analysis, it is assumed that the DSMS again has perfect information about the electromagnetic environment, the RF characteristics of the systems in the band, the operational configuration, and time domain usage information at its disposal to manage spectrum access. This allows the DSMS to implement a variety of algorithms that can optimize on any element within the dataset. In the COA 1+2 analysis, the algorithm selected implements the received power culling method, which seeks to minimize the number of base stations required to turn off the occupied frequencies.

The associated interference suppression value is then inserted into the link budget equation to account for the interference mitigating technique where appropriate. For COA 1 + COA 2, the interference mitigation features were analyzed in conjunction with a DSMS: Physical Resource Block (PRB) Blanking, Beam Muting, and Null Steering, the associated interference suppression values from the COA 1 analyses are inserted into the link budget equation to account for the technique where appropriate. In light of the temporal usage information envisioned to be communicated to the 5G base station, when the USG radar is not in use, normal 5G operations may resume.

6.13.5.2 COA 1 + COA 2 Modeling Assumptions

Multiple assumptions were made in the setup and execution of the COA 1+2 analysis and are summarized below:

1. The DSMS has perfect information about the electromagnetic environment, the RF characteristics of the systems in the band, the operational configuration, and time domain usage information at its disposal to manage spectrum access while ensuring no harmful interference to USG radars.

2. The DSMS has the authority to exert command and control over the 5G base stations.

3. The DSMS implements the received power culling algorithm, turning off base stations until the aggregate received power at each pointing angle is below the interference threshold.

4. Base stations that are not turned off are employing an active 5G RAN interference mitigation technique within the COA activation distance. (COA 1+2)

5. 1-way analysis modeling interference from 5G transmitters into USG radar receivers.

[redacted]

[redacted]

[redacted]

6.13.5.3 COA 1 + COA 2 Link Budget Summary

The link budget summary is shown in **Tables 6.28-6.30** below for COA 1+2 analyses, with the differentiators highlighted.

TABLE 6.28. COA 1+2: PRB BLANKING + DSMS LINK BUDGET SUMMARY					
Variable		**Macro**	**Outdoor Micro**	**Indoor Micro**	**Radar**
EIRP (dBm)	Urban/Suburban/ Rural	72/58/47	29	24	
	FCC Rural	75/61/47			
Ant. Height (m)	Urban	20	6	(5,10,15 ,20, etc.)	
	Suburban	25			
	Rural	35			
PRB Blanking (dB)		-25	-25	-25	0
Ant. Pattern		3 Sector AAS	Omni	Omni	
Clutter Loss		P.452	P.2108	P.452 or P.2108	
Network Loading (dB)		-5.23 (30%)			
TDD Factor (dB)		-1.25 (75% DL)			
Propagation Loss		TIREM 6			
FDR					MSAM
Polarization Mismatch Loss (dB)					[redacted]
Ant. Pattern					Measured or STATGAIN
Ant. Height					ORV Supplied
Culling Method		Received Power Contribution			

Table 6.28: COA 1 + COA 2: PRB Blanking + DSMS Link Budget Summary

TABLE 6.29. COA 1+2: BEAM MUTING + DSMS LINK BUDGET SUMMARY					
Variable		**Macro**	**Outdoor Micro**	**Indoor Micro**	**Radar**
EIRP (dBm)	Urban/Suburban/Rural	72/58/47	29	24	
	FCC Rural	75/61/47			
Ant. Height (m)	Urban	20	6	(5,10,15,20, etc.)	
	Suburban	25			
	Rural	35			
Beam Muting (dB)		-10	**0**	**0**	**0**
Ant. Pattern		3 Sector AAS	Omni	Omni	
Clutter Loss		P.452	P.2108	P.452 or P.2108	
Network Loading (dB)		-5.23 (30%)			
TDD Factor (dB)		-1.25 (75% DL)			
Propagation Loss		TIREM 6			
FDR					MSAM
Polarization Mismatch Loss (dB)					[redacted]
Ant. Pattern					Measured or STATGAIN
Ant. Height					ORV Supplied
Culling Method		Received Power Contribution			

Table 6.29: COA 1 + 2: Beam Muting + DSMS Link Budget Summary

TABLE 6.30. COA 1+ COA 2: NULL STEERING + DSMS LINK BUDGET SUMMARY					
Variable		**Macro**	**Outdoor Micro**	**Indoor Micro**	**Radar**
EIRP (dBm)	Urban/Suburban/Rural	72/58/47	29	24	
	FCC Rural	75/61/47			
Ant. Height (m)	Urban	20	6	(5,10,15,20, etc.)	
	Suburban	25			
	Rural	35			
Null Steering (dB)		-30	**0**	**0**	**0**
Ant. Pattern		3 Sector AAS	Omni	Omni	
Clutter Loss		P.452	P.2108	P.452 or P.2108	
Network Loading (dB)		-5.23 (30%)			
TDD Factor (dB)		-1.25 (75% DL)			
Propagation Loss		TIREM 6			
FDR					MSAM
Polarization Mismatch Loss (dB)					[redacted]
Ant. Pattern					Measured or STATGAIN
Ant. Height					ORV Supplied
Culling Method		Received Power Contribution			

Table 6.30: COA 1+2: Null Steering + DSMS Link Budget Summary

6.13.5.4 COA 1 + COA 2 Result Graphics

COA 1 + COA 2 results plots, as shown in **Figures 6.29-6.31** below, build upon the concepts and depictions from COA 2 results graphics and again show the baseline separation distance for comparison. Like COA 2, the DSMS has all the information needed to optimize the spectrum sharing solution for a given scenario/environment, the minimum number of base stations are required to turn off the occupied frequencies to enable co-existence. These represent a snapshot in time and would change as the locations of the radar or the 5G devices change. The yellow squares and circles are base stations that have implemented the COA 1 interference mitigation technique of interest. The red squares and circles are base stations that must turn off the occupied frequencies to avoid causing harmful interference in the aggregate to the USG radar. The green circles and squares are permitted to maintain normal operations.

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

CHAPTER 7: SUMMARY OF RESULTS

Sharing of the 3100-3450 MHz band between Federal USG and commercial systems is not feasible unless the conditions in Section 8.4 are met and a sufficient coordination framework is fully proven through rigorous, in-depth, real-world full scope operational testing with Joint Force assets and implemented to facilitate spectrum sharing in the time, frequency, and geography domains. Specifically, pursuing a dynamic spectrum management system (DSMS) that evolves the implementation of Citizens Broadband Radio Service (CBRS) in the 3550-3700 MHz band, presents a potential spectrum sharing framework between the Federal USG systems and commercial systems in the band and auction of frequencies therein. Combining the DSMS with the advanced interference mitigation features investigated through the Active 5G RAN COA could improve efficiency and effectiveness of the spectrum use if fully proven through rigorous, in-depth, real-world full scope operational testing with Joint Force assets. While the creation of a coordination framework could make sharing technically feasible, commercial availability of the spectrum will continue to be impacted by critical airborne systems in the band that will trigger additional spectrum access limitations. While the creation of a coordination framework would make sharing feasible, commercial availability of the spectrum will continue to be impacted by critical airborne systems in the band that will trigger additional spectrum access limitations. Even with stringent adherence to a coordination framework and the conditions discussed in Section 8.4, spectrum sharing between Federal and non-Federal users in the 3100-3450 MHz band will remain challenging.

7.1 Introduction

To determine the potential COAs and assess their viability, the following steps were taken consistent with Congress's statutory directive for sharing.

1. The Department worked with the PATHSS TG to develop specific spectrum sharing COAs to support the detailed technical studies by DoD carried out under EMBRSS.

2. Using the spectrum sharing COAs developed with the PATHSS TG and technical presentations by PATHSS TG members, options were identified for spectrum sharing methodologies and frameworks in the 3100-3450 MHz band consistent with current 5G wireless broadband technologies. Although the technical analysis focused on 5G technologies, each COA takes into account extensibility and the evolution of technology.

3. Finally, the DoD CIO-led analysis of the COAs and technologies resulted in the presentation of DoD findings to leadership.

Assessing overall feasibility of sharing spectrum between non-Federal and Federal systems in the 3100-3450 MHz band requires a comprehensive assessment of many factors. The feasibility assessment utilized an evaluation framework to assess each COA against a set of factors that are critical to understanding the feasibility of spectrum sharing in this band.

This chapter explains the COAs in detail and the COA evaluation framework. As noted in **Chapter 3**, DoD explored a range of proposed COA scenarios to ensure the feasibility assessment covered a wide range of viewpoints. Per the definition of spectrum sharing that guided PATHSS TG activities, this requires that the proposed COAs: (1) do not cause harmful degradation or interference; (2) do not result in a loss of access to the spectrum; and (3) do not include vacating, compression, or repacking of the spectrum. As noted earlier, as part of a collaborative effort that is foundational to the EMBRSS feasibility assessment, the COAs reflect PATHSS members' ideas for spectrum sharing interference mitigation and coordination in the 3100-3450 MHz band and serve as the basis for the analysis.[71] Gathering these COAs collaboratively ensures that DoD is including a comprehensive viewpoint in the analysis of 3100-3450 MHz. Each COA includes an assessment against each factor in the evaluation framework. Finally, it provides an overall assessment of the feasibility of spectrum sharing in the 3100-3450 MHz band while ensuring no impact to the primary mission of military spectrum users in the band through the loss of critical DoD capabilities.

The guiding assumptions are included in **Chapter 5**, with additional details about the technical analysis assumptions provided in **Chapter 6**. The technical assumptions are repeated in each results section for ease of reference.

The intent is that, if the conditions in Section 8.4 are met, the spectrum sharing frameworks ensure continued DoD access to the 3100-3450 MHz band, including accommodation of frequency assignments for future systems. An assumption from a regulatory standpoint is that DoD and other Federal systems would retain a primary allocation in this spectrum range, consistent with current U.S. policy positions, to enable this outcome as part of ultimate sharing arrangements. This report finds that a spectrum coordination framework is necessary to effectuate sharing across the entire frequency range. Because Congress tasked the Department with assessing the feasibility of making frequencies within the 3100-3450 MHz band available on a shared basis, the DoD determined that the nationwide, dynamic scope of missions by Federal incumbent systems necessitated consideration of a dynamic access mechanism for non-Federal users. The scope, terms, and implementation of any such mechanism is beyond the scope of this report and will be subject to future regulatory proceedings with respect to service rules for the band. A baseline expectation is that as operational needs evolve, DoD will require the ability to request and add frequency assignments to this spectrum range in the future.

Without pre-judging the outcome of any specific regulatory proceedings, the evaluation below is predicated on a baseline assumption that a DSMS capability, combined with some of the advanced interference mitigation features of the active 5G RAN COA, will need to address operational security considerations. USG Federal users have unique security concerns related to information that will be collected or disseminated as part of a future notification framework. Development of security protocols will be needed in coordination with industry, Federal incumbent users and national policymakers.

7.2 COAs Overview

[71] *See* PATHSS PAR, which stated: "The critical constraint guiding DoD's examination of the band is that proposed sharing frameworks and their concomitant policy, standards and technology implications must safeguard the primary mission of the military activities in the covered band."

[redacted]

This subsection will evaluate the spectrum sharing COAs that were approved as part of the PATHSS TG. A description of COAs 1-3 is included below. COAs 1-2 were subject to the technical feasibility assessment described in Chapter 6. COA 3 - Radar Third Generation Partnership Project (3GPP) Interference Cancellation - was studied through prototype development and demonstration and deemed too immature to conduct a full technical analysis as in COAs 1 and 2.

TABLE 7.1: EMBRSS COA DESCRIPTIONS AND IMPLEMENTATION RESPONSIBILITY

COA	**Name**	**Short Description**	**Responsibility for Implementation**
1	Active 5G Radio Access Network (RAN)	This COA enables spectrum sharing by having 5G network operators implement interference mitigation features in the 5G RAN base stations in response to the sensed presence of Federal system operation.	Non-Federal
2	Dynamic Spectrum Management System (DSMS)	This COA enables frequency sharing through a centralized coordination system, similar to a Spectrum Access System (SAS) as used in Citizens Broadband Radio Service (CBRS) or Automated Frequency Coordination (AFC) systems. DSMS can direct 5G base stations to temporarily curtail operation to protect the Federal system or mission and resume normal operation when the potential for interference to the Federal system or mission is no longer present.	Shared Responsibility
3	RADAR 3GPP Digital Interference Cancellation	This COA enables frequency sharing through the use of a programmable 3GPP signal digital canceller on the DoD RADAR receiver.	Federal

Table 7.1: EMBRSS COA Descriptions and Implementation Responsibility

The EMBRSS COA Evaluation Framework is separated into three primary Assessment Areas: Technical, Operational, and Programmatic (see Table 7.2). Each Assessment Area has associated factors and descriptions. Each section describes the COA and evaluates each of the assessment area factors. Just as this report does not address specific implementation challenges in the non-Federal domain, each assessment will need to be reviewed by the military departments by mission and by system in greater detail as part of any future implementation plan. Furthermore, detailed estimates for eligible sharing costs under the Spectrum Relocation Fund (SRF) and associated timelines would need to be addressed as part of a Transition Plan submitted

[redacted]

to the Technical Panel prior to an auction. Therefore, precise cost and schedule estimates are not possible at this time.

TABLE 7.2: EMBRSS COA EVALUATION FRAMEWORK EVALUATION FACTORS

Assessment Area	Factor	Description
Technical	Baseline Technical Results	Separation distance required to protect Federal radar systems from interference from a mature 5G deployment when operating co-channel without a spectrum sharing framework in place. These results represent the status quo if 5G were to be deployed co-channel to existing Federal systems
	COA Technical Results	Improvement in spectrum availability as compared to the baseline. Presented in terms of the change in the geographic separation distance required and the number of base stations impacted
	Extensibility	The ability for the COA to address future needs, including new Federal systems or operational areas and the evolution of commercial networks (e.g. Next G, xG) and associated use cases
	Maturity	Developmental state of the foundational technology necessary to implement, deploy, and effectuate the COA
Operational	Operational Coordination	Coordination and policy mechanisms at the Service, DoD, and interagency levels needed to support system performance
	Manpower and Training	Manpower and training needed to support system performance
	System Impacts	The effects on system technical performance and capability
	Readiness	Ability to maintain current and future operational readiness requirements
	Security	Secure and avoid compromise of Operations, Cyber, and Information

[redacted]

TABLE 7.2: EMBRSS COA EVALUATION FRAMEWORK EVALUATION FACTORS		
Assessment Area	Factor	Description
Programmatic	System Replacement or Hardware/Software Cost Impacts	Aircraft platform integration costs and schedule usually exceed hardware purchases; and programmatic hardware/software replacement or complete system replacement costs to DoD systems to operate in this COA are estimated
	Training Impacts	Estimated training requirements for DoD personnel to operate DoD systems in this COA
	Organization Infrastructure	Estimated organizational infrastructure requirement to monitor, coordinate, and report spectrum use
	Schedule	Estimated schedule impacts that will drive the implementation of the COA

Table 7.2: EMBRSS COA Evaluation Framework Evaluation Factors

The COAs provide approaches that commercial systems can take to protect DoD systems and the missions they support. It is essential to U.S. national security interests that sensitive technical information and Operational Security (OPSEC) be protected within any COA that is employed. As noted above, the unique security concerns and OPSEC considerations of USG Federal missions will be an important regulatory consideration during the development of a service rule regime. Flight paths and other information pertaining to DoD airborne systems will need to be protected due to the sensitive nature of the operations they support. DoD ground systems operations may pose OPSEC concerns as well. All the COAs present security challenges – some common and others unique to specific sharing methods. The sections that follow focus on the primary features of each COA that will need to be thoughtfully and systematically addressed to appropriately mitigate vulnerabilities. DoD will incorporate OPSEC into all aspects of spectrum coexistence. Emphasis areas include sharing technical data, classification guidance, protection of coordination mechanisms, detection of location and other operational parameters of Federal systems and protecting DoD systems from vulnerabilities associated with interagency and non-Federal coordination. To do so, DoD will closely adhere to existing processes to thoroughly review necessary sharing information to preserve security of DoD systems and operations. In some cases, the DoD will need to work with partners and allies conducting operations with US Forces to obtain system parameters and other technical data so they can be incorporated into the sharing framework.

The evaluation in this chapter is often written in terminology that is typical to describe impacts to DoD. The overall scope of the feasibility assessment, however, included other Federal agencies (i.e., Department of Homeland Security and U.S. Coast Guard) that operate systems in this band of spectrum and have operations that would be directly or indirectly impacted by spectrum

[redacted]

sharing. If the recommended COAs of this report – DSMS combined with the advanced interference mitigation features of Active 5G RAN – are implemented, similar considerations would need to be applied within those agencies to maintain mission effectiveness.

7.3 Baseline Technical Analysis

7.3.1 Objective

The objective of the baseline analysis is to establish the required geographic separation distance between Federal systems and 5G base stations when operating co-channel, to ensure no harmful interference is experienced by the Federal systems absent the implementation of any spectrum sharing COA. The baseline is then used to compare the COA technical analysis results and to quantify their relative effect on the geographic separation distances required to protect the Federal systems.

7.3.2 Approach

The baseline analysis simulates three different power level scenarios for 5G deployment. Additional details—including the modeling assumptions, the approach, and an introduction to interpreting the graphical results—are contained in Section 6.11. For the full results of each system in the band, see **Appendix C**.

7.3.3 Baseline Assumptions

Assumptions made in the setup and execution of the baseline analysis are summarized below:

1. One-way analysis modeling interference from 5G transmitters into USG radar receivers.

2. No coordination between users.

3. The only information that is known to 5G operators is the approximate location and/or area of operation of a given radar, the tuning range of the radar, and the radar's geographic separation distance requirement.

4. Base station signals are fully powered down within the separation distance radius.

5. Base stations beyond the geographic separation distance operate normally.

[redacted]

[redacted]

[redacted]

7.3.4 Baseline Technical Results

Geographic separation distance is required to protect Federal radar systems from harmful interference from a mature 5G deployment.

Priority systems used in the analysis include representative systems from each Federal agency and MILDEP, including ground-based, shipborne, and airborne radars. These systems were used as a simplified, representative example of the radar use cases and platform types that need to be considered for a coexistence framework.

DoD identified 16 priority systems to reflect representative systems across three separate environments: airborne, shipborne, and ground-based. The following figures represent the geographic impact of the 16 priority systems analyzed. Importantly, there are additional systems which have also been considered in this analysis and not all systems analyzed are co-located with the 16 priority systems pictured throughout this report. However, resolving the sharing framework for these 16 priority systems will support sharing across all Federal systems. For full results, see **Appendix C**.

[redacted]

[redacted]

Based on the significant geographic impact caused by the large number of base stations modeled as needing to cease operation at the assumed heights and power levels to protect mobile system operation, along with the nationwide, mission-critical airborne operations in the band, a feasible spectrum sharing approach based on designating exclusive operating zones for Federal systems alone was not identified in this report's analysis framework. The Department, therefore, recognizes that a spectrum sharing framework is necessary that can provide flexible geographic protection for Federal missions.

The assessments of the COAs below and the associated baseline technical analysis focus on coordination with and impact on shipborne and terrestrial systems. Moreover, because of the pervasive nature of shipborne and terrestrial Federal systems itinerant use, any successful sharing of the band will necessitate a coordination framework across the time domain. The reduction in geographic separation distance is required to protect Federal ground based and shipborne radar missions from interference from a mature 5G deployment. In addition, as stated above, commercial availability of the spectrum will be limited by the ongoing necessity of mission-critical airborne missions in the band.

The Active 5G RAN COA (COA 1) and the DSMS COA (COA 2) can be compared to the baseline result using two metrics: 1) a reduction in the geographic separation distance, and 2) a reduction in the number of base stations required to vacate the spectrum occupied by the radar to eliminate harmful interference.

7.4 COA 1: Active 5G Radio Access Network (RAN)

TABLE 7.3: ACTIVE 5G RADIO ACCESS NETWORK (RAN) COA DESCRIPTION				
COA	**Name**	**Short Description**	**Access to Band**	**Responsibility for Implementation**
1	Active 5G Radio Access Network (RAN)	This COA enables frequency sharing by having 5G network operators implement interference mitigation features in their 5G RAN base stations in response to the presence of Federal system operation.	Federal is primary and Non-Federal uses are secondary consistent with current U.S. policy	Non-Federal

Table 7.3: Active 5G Radio Access Network (RAN) COA Description

The PATHSS TG defined the Active 5G RAN COA, with the general characteristics that would guide analysis of this COA described in the quad chart approved on May 11, 2022. The quad chart describing this COA is included in **Figure 7.3** below. The following sections describe some of the details of the COA used as the basis for this analysis.

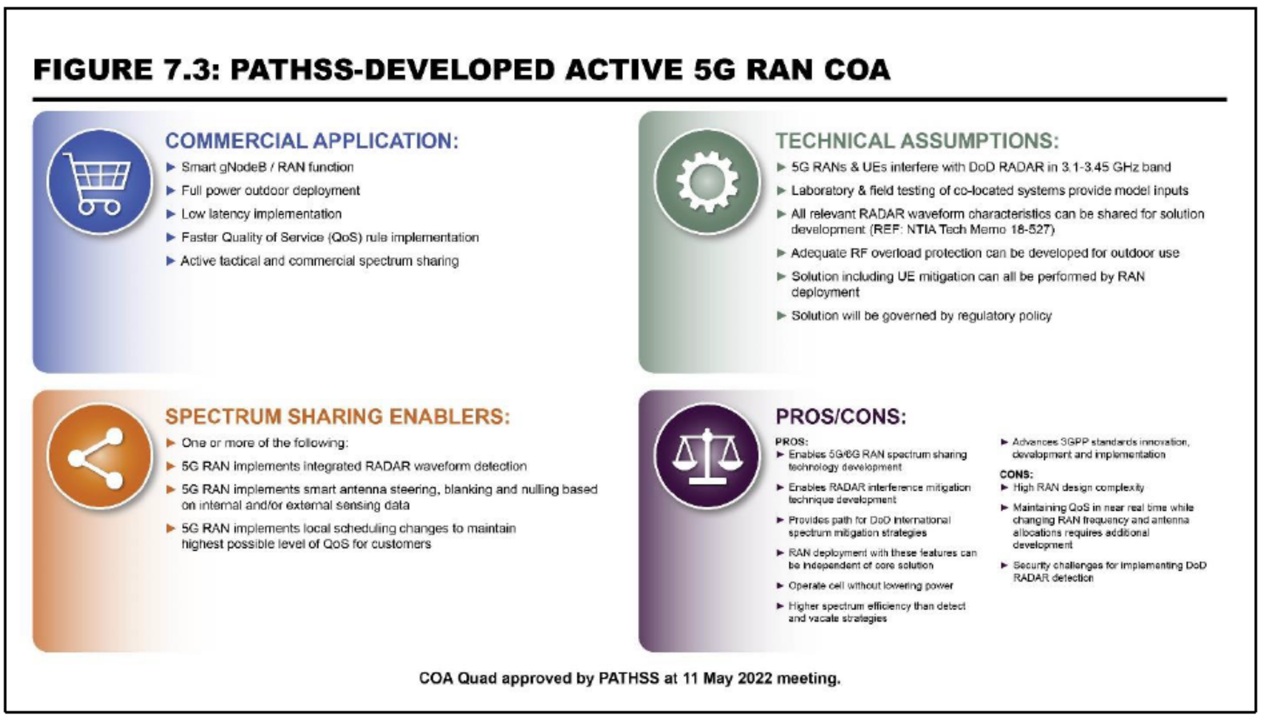

Figure 7.3: PATHSS-Developed Active 5G RAN COA

[redacted]

The 5G RAN is the portion of the 5G network that controls all radio functions. This includes scheduling users, radio-resource handling, transmission protocols, coding, power control, and antenna schemes. The foundation of this COA is that 5G RAN can modify 5G base station operation in response to changes in the electromagnetic spectrum environment to avoid causing interference with the Federal radar system in the band.

In this COA, the presence of the Federal system is determined through an integrated system that senses the electromagnetic spectrum environment, as described above. For the purposes of this graphic, the decision engine is depicted as the logical architectural element where reasoning is done to translate the knowledge of a Federal system operating in the band (determined through sensing), and the decision to modify the 5G system behavior is made. The modification of 5G system behavior would include invoking interference mitigation technique(s), as described later in this section.

A diagram of how this COA could be implemented is shown in **Figure 7.4** below.

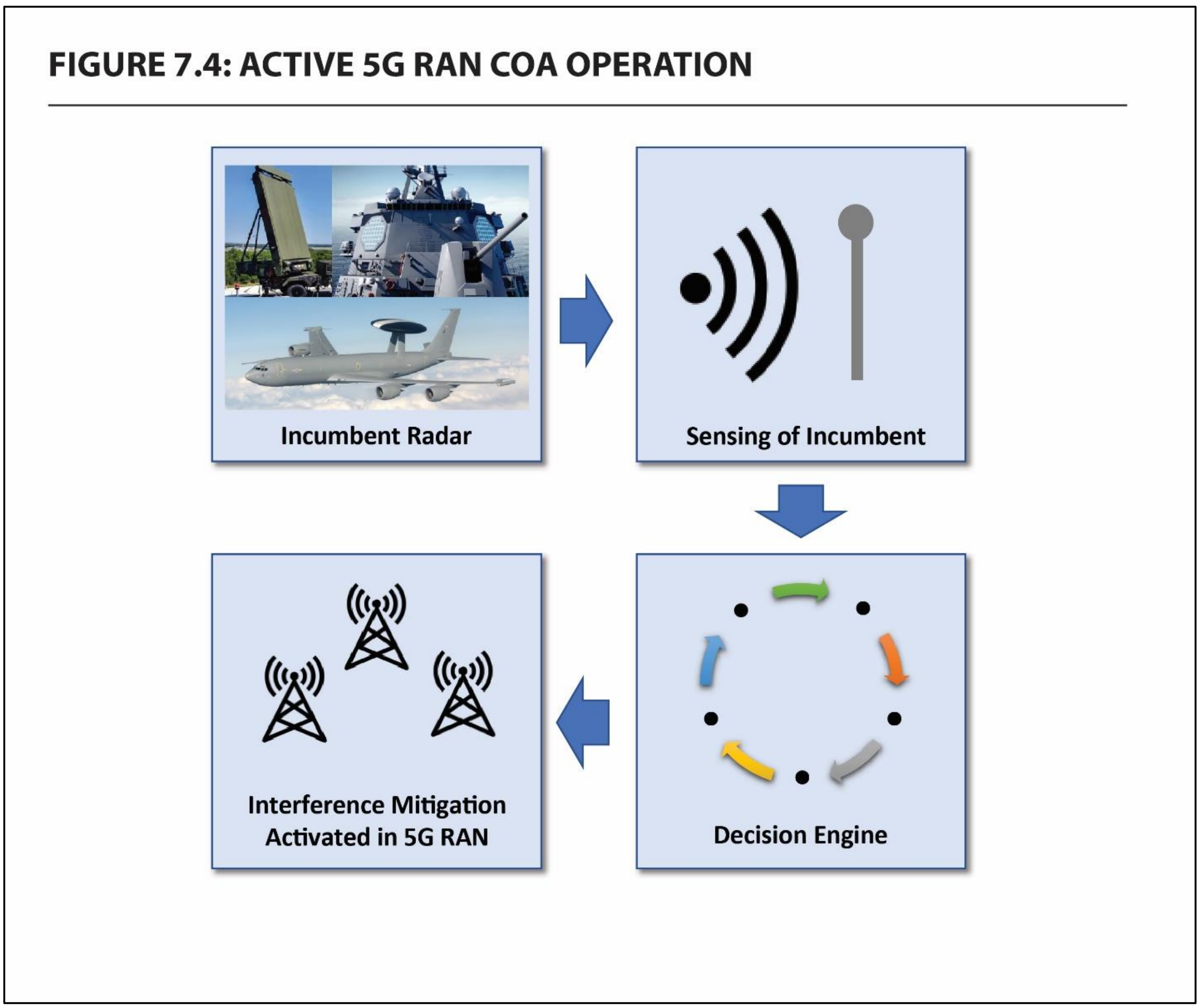

Figure 7.4: Active 5G RAN COA Operation

[redacted]

7.4.1 Federal System Sensing

A sensing solution would follow a “detect and avoid” approach to spectrum coexistence in the band. The effectiveness of this COA directly depends on the accuracy and reliability of detecting Federal radar emissions. While each implementation of an Active 5G RAN would vary in design and implementation, the solutions are all expected to employ signal processing techniques to identify radar operations within the monitored spectrum. This information is a vital input for the decision engine to determine how to best apply the mitigation features of the base station to avoid interference to Federal systems and missions.

A sensing solution could be integrated within the 5G RAN or could be deployed as an external sensing network. Due to the nationwide operations in this band, a vast network of sensors would be needed to inform the 5G network of Federal operations. An external sensing network, known as an Environmental Sensing Capability (ESC), has been implemented in the Citizens Broadband Radio Service (CBRS) 3550-3700 MHz band, and provides a reference for how an external sensing capability could be employed within the 3100-3450 MHz band. Because of the wide variety of radar systems operating in the 3100-3450 MHz band, the sensing capability would need to be able to sense radars with many different operating characteristics. The sensing information is then processed by a policy engine that is able to reason against the detection information and translate it to the appropriate commands to the desired interference mitigation actions at the 5G base station. The mitigation actions taken by the 5G base station could differ based on the 5G base station capability as long as the appropriate threshold of interference protection is achieved.

7.4.2 Interference Mitigation Features

The specific interference mitigation techniques that can be utilized may differ depending on the capabilities of the 5G base station and the level of interference mitigation needed for a particular spectrum coexistence scenario. The interference mitigation techniques analyzed as part of this COA include: beam muting, beam nulling (null steering), and Physical Resource Block (PRB) blanking. Other interference mitigation techniques may be possible to optimize spectral coexistence, and those could be considered as part of an Active 5G RAN implementation and included as they evolve and mature.

Physical Resource Block (PRB) Blanking

One technique to reduce interference to the radar is for 5G to avoid using the set of time-frequency resources that can affect radar transmission and reception. The time-frequency resources used by the 5G base station are referred to as 5G Physical Resource Blocks (PRBs) and constitute a set of time and frequency resources used for 5G uplink and downlink transmissions. PRB Blanking is the technique where a 5G base station avoids allocating designated resource blocks in the interference region for uplink or downlink traffic.

[redacted]

When looking at the frequency domain, PRB blanking can create a notch-like reduction in power across a portion of the frequency spectrum, where the power coming from the 5G network is depicted as a reduction of power over a certain frequency. **Figure 7.5** below provides an example of how this would present over the 5G signal.

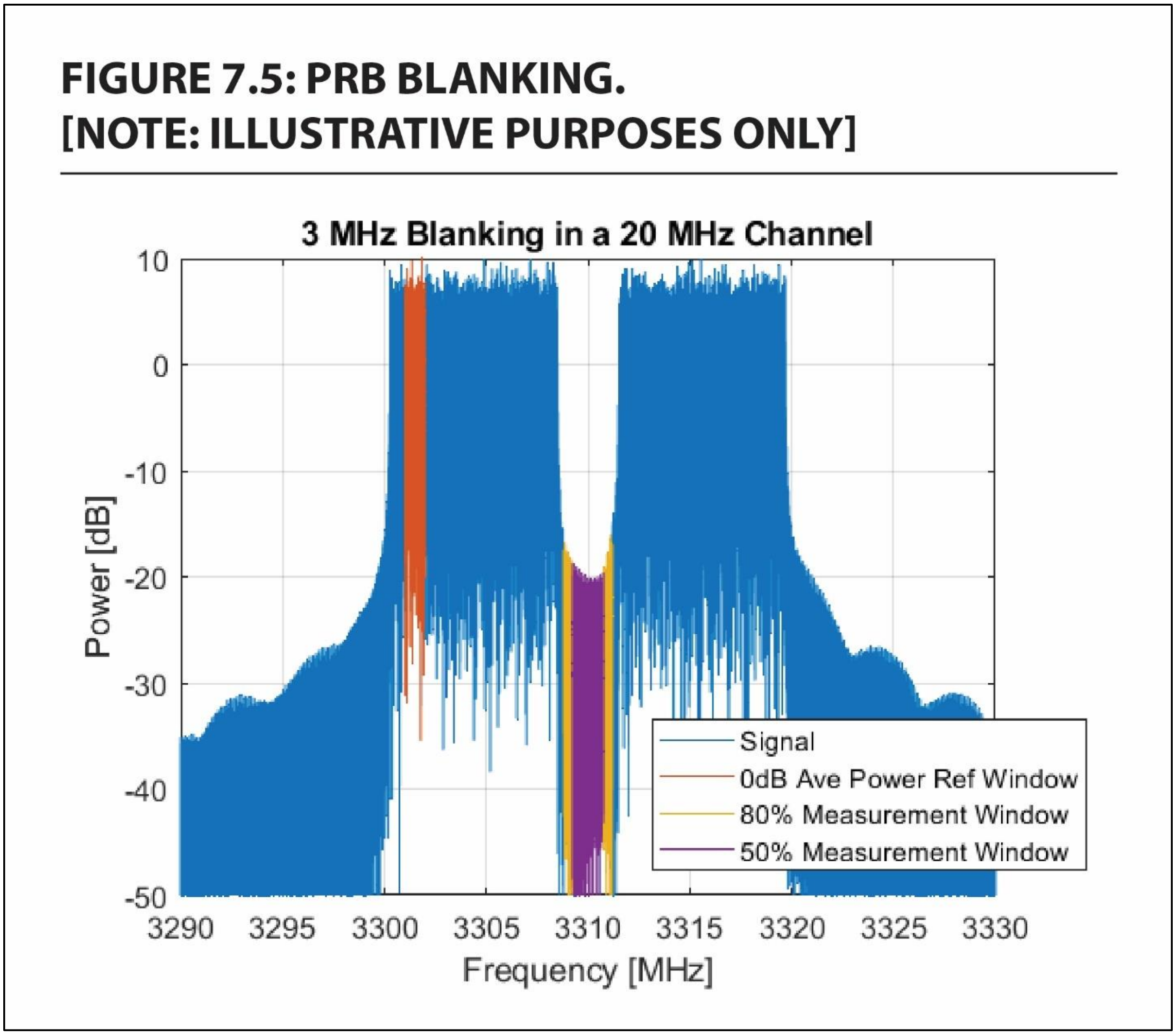

Figure 7.5: PRB Blanking. [Note: figure is for illustrative purposes only, and not meant to identify specific values utilized in the technical analysis of this feasibility assessment]

Beam Muting

Beamforming is a signal processing technique used in 5G that enables directional transmission or reception. This allows the 5G base station to more selectively concentrate its transmit power in a particular direction at a particular time to a particular area (or device). In general, beamforming improves overall network efficiency and performance.

[redacted]

[redacted]

Most 5G networks utilize a grid-of-beams approach, whereby a configurable number of ‘coarse’ beams are used for Synchronization Signal Block (SSB) transmission. An example baseline configuration for a 5G network testing is a 3-3-2 pattern, as depicted in **Figure 7.6** below. Beam muting is a mitigation technique that allows for one or more SSB beams to be precluded from transmissions (muted), which can reduce the amount of power directed toward a detected radar system. A notional example is provided in the figure below.

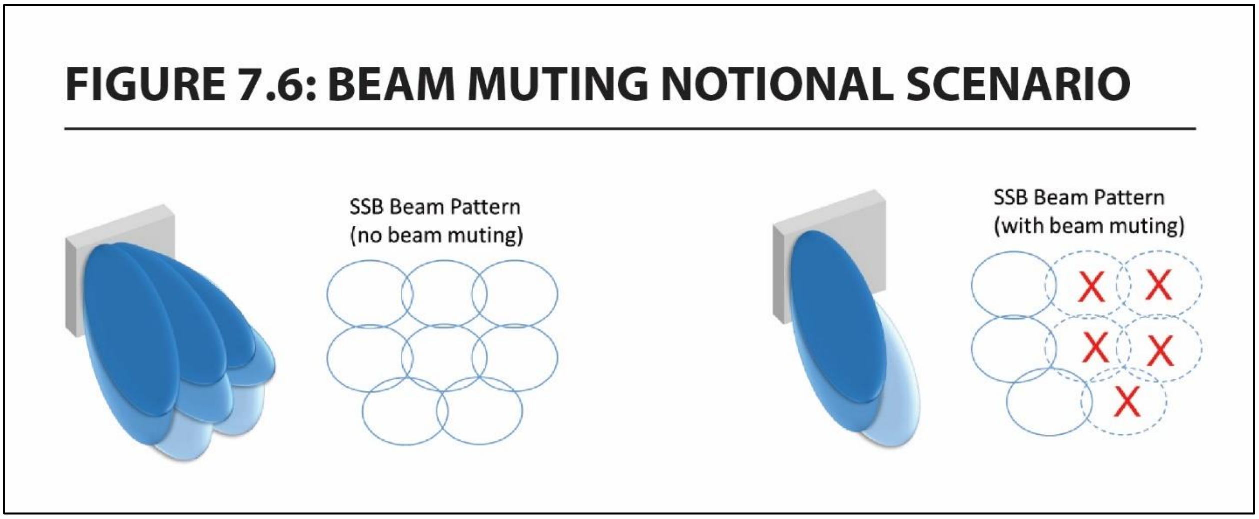

Figure 7.6: Beam Muting Notional Scenario

Null Steering

Null steering refers to the creation of nulls in the transmitter or receiver antenna array patterns to mitigate interference from a 5G base station to the radar receiver. By detecting and determining the angles of arrival of the interference, the 5G base station can be configured to phase shift the array, creating nulls in the beam pattern to mitigate interference in both azimuth and elevation. **Figure 7.7** below shows an example of an antenna pattern with null steering in azimuth.

[redacted]

[redacted]

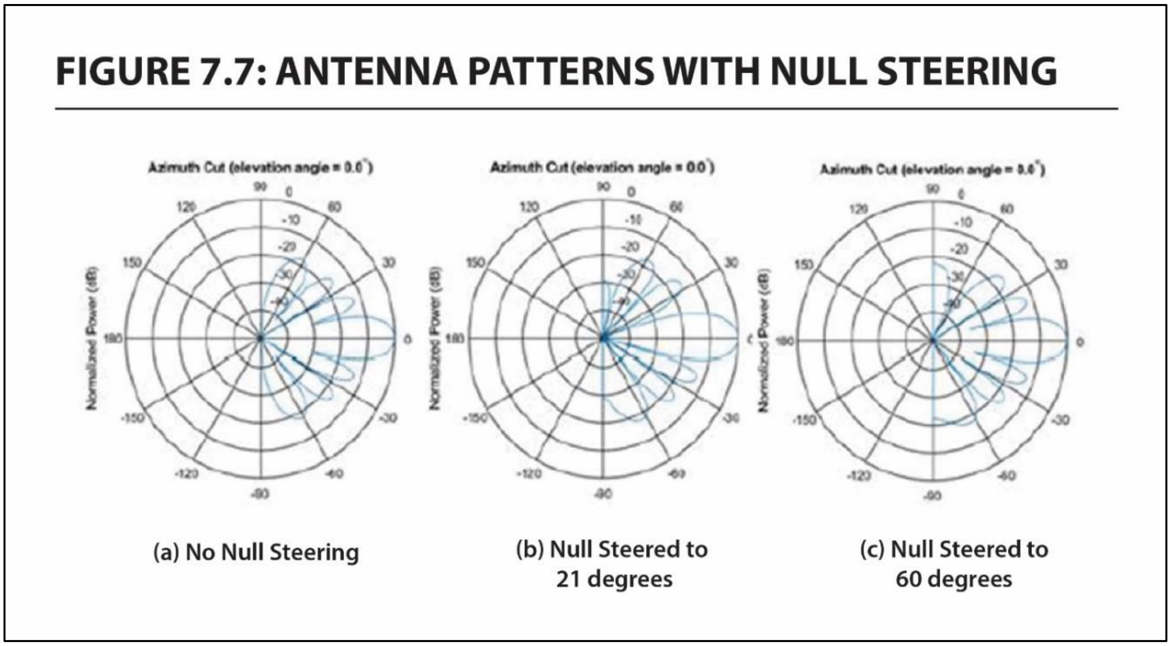

Figure 7.7: Antenna Patterns with Null Steering

Other Interference Mitigation Techniques

The three interference mitigation techniques noted above were specifically analyzed because they were discussed within the COA development process of the PATHSS Task Group. Those techniques were defined such that the feasibility assessment could analyze specific interference mitigations in a modeled scenario. The COA is intended to be flexible and additional techniques could be utilized if they provide adequate protection to Federal systems.

7.4.3 Active 5G RAN Technical Evaluation

The Active 5G RAN technical evaluation is composed of three areas: Results, Extensibility, and Maturity.

The methodology and technical details used to model the Active 5G RAN for the results are described in **Chapter 6**. The following analysis results show the coordination distances modeled to protect Federal radar systems from interference with a mature 5G deployment when a spectrum sharing framework is in place. The results depicted are representative based on the inputs available at the time the analysis was conducted. These analysis results are not intended to be definitive as related to a final spectrum sharing implementation in the band. Additional, site-specific analysis, informed by field trial data and analytical model calibration, would be appropriate to refine a spectrum sharing framework for the band, utilizing the best input data available at the time, and open to evolution as deployments evolve.

COA 1 – 5G RAN Objective

The objective of the COA analyses is to quantify each 5G RAN COA mitigation and its ability to improve spectrum sharing opportunities between the USG and 5G systems in the band.

[redacted]

Modeling Approach

The Active 5G RAN COA includes PRB Blanking, Beam Muting, and Null Steering. A determination of the amount of interference suppression achievable for each technique is based on analysis, measurements, and subject matter experts' evaluation of each approach, as available. The associated interference suppression value is then inserted into the link budget equation, as a reduction, to assess the spectrum-sharing improvements for the technique. Using the new aggregate interference power values, the required separation distance is then recalculated to determine the spectrum-sharing benefit of the technique.

For COA 1, the interference suppression values used for each interference mitigation technique are included in **Table 7.3** below.

TABLE 7.4: MODELED INTERFERENCE SUPPRESSION VALUES	
Interference Mitigation Technique	**Interference Suppression Value**
PRB Blanking	-25 dB
Beam Muting	-10 dB
Null Steering	-30 dB

Table 7.4: Modeled Interference Suppression Values

Additional details for the modeling approach and an introduction to interpreting the graphical results are contained in Section 6.12 and Appendix A. For the full results for each system in the band, see **Appendix C**.

Assumptions

Multiple assumptions were made in the setup and execution of the COA 1 analysis and are summarized below:

1. The 5G base station is aware of the radar's location, occupied frequencies, separation distance at which interference mitigation is required, and separation distance at which the occupied frequencies must be vacated. (COA 1 Only)

2. All capable base stations within the activation distance are implementing the interference mitigation technique under investigation. (COA 1 Only)

3. It is assumed that the maximum blanking region for PRB Blanking is half the channel bandwidth. Therefore, the maximum blanked region would be 50 MHz for a 100 MHz

5G channel. PRB-Blanking is not feasible as an interference mitigation technique for radars with receive bandwidths over 50 MHz, or for radars who employ frequency hopping. (COA 1 Only)

4. The analysis implements the nearest neighbor culling algorithm, turning off base stations (full power down) until the aggregate received power at each pointing angle is below the interference threshold. (COA 1 Only)

5. The geographic separation distance is defined as the distance from the radar to the furthest base station that is required to vacate the occupied frequencies.

6. One-way analysis modeling interference from 5G transmitters into USG radar receivers.

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Technical Results

Nearly all of the mitigation techniques modeled produced a reduction in the number of 5G base stations required to completely cease operation in the presence of a Federal system. This is particularly true with respect to shipborne and terrestrial systems, where all mitigation techniques produced improvements. Moreover, combining these techniques could produce even greater sharing between 5G and Federal systems. However, based on the significant geographic impact in the 5G deployment scenarios that were analyzed, challenges associated with a 5G base station timely sensing the presence of distant airborne Federal systems, and OPSEC considerations commercial availability of the spectrum will be limited by the ongoing necessity of mission-critical DoD systems in the band. While the creation of a coordination framework would make sharing feasible, commercial availability of the spectrum will continue to be impacted by critical airborne systems in the band that will trigger additional spectrum access limitations.

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The following Priority systems in **Figures 7.14-7.19** are histograms that represent the 16 priority systems we analyzed. The USG systems chosen to be represented in Figures 7.14-7.19 are the scenarios that produced the largest baseline geographic separation distance for that specific USG system along with their respective COA 1 results. These represent the base stations turned off for Baseline vs COA 1. For the full results of all systems, see **Appendix C**.

[redacted]

[redacted]

PRB Blanking is assumed to apply to a maximum of half the channel bandwidth of the 5G system to still allow capacity in the channel. With a maximum 5G channel bandwidth of 100 MHz, the maximum blanked region is 50 MHz. Therefore, PRB blanking is only a potential interference mitigation feature for USG systems that have a bandwidth of less than 50 MHz. Additionally, PRB Blanking is not applicable for systems that employ frequency hopping.[72] [redacted]

[72] See **Figures 7.18 and 7.19**, which show PRB Blanking not applicable for [redacted] and Ground Based Radar 1, Radar 2, Radar 3, and Radar 5 systems due to system bandwidth and frequency hopping.

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[redacted]

[redacted]

[redacted]

[redacted]

Active 5G RAN interference mitigations provide significant improvement when compared to baseline operation. However, a substantial number of base stations must implement Active 5G RAN interference mitigation to improve upon the baseline separation distance

7.4.4 Active 5G RAN Extensibility

Extensibility is assessed as the ability for the COA to address future Federal needs, including new systems or operational areas, as well as the evolution of commercial networks and associated use cases. A COA implementation that offers the most flexibility will offer the greatest ability to adapt and accommodate new spectrum sharing scenarios as the wireless ecosystem evolves and spectrum sharing requirements change over time.

Features in the Active 5G RAN COA that could be implemented through software versus hardware changes provide the greatest flexibility and lowest cost to extend to new spectrum sharing requirements. The specific features that are software-defined versus hardware-defined will vary between vendor designs, and some features will be limited by a combination of software and hardware. For example, the choice of antenna utilized in the initial deployment will provide a limiting factor as to how beam muting and/or beam nulling could be implemented, but changes in the software could alter the emission characteristics of the antennas as needed to support and optimize a spectrum sharing scenario.

Overall, the Active 5G RAN COA is considered to have a high level of extensibility because of the control over the RAN interference mitigation features and anticipated evolution and refinement of these features over time.

7.4.5 Active 5G RAN Maturity

Maturity is assessed as the developmental state of the foundational technology necessary to implement and field the COA. A COA implementation that is based on proven technology that has gone through the development process, including testing and field trials (or been previously fielded), is considered at a higher maturity than a technology that is still in the prototype or experimental stages.

The interference mitigation techniques analyzed in this feasibility assessment—PRB blanking, beam muting, and null steering—are at varying levels of maturity. While some of these features may be available in 5G equipment in the near-term, initial deployments are expected to be fairly static such that the configuration of the feature within the 5G network cannot change in real-time. Changing the network configuration from a standard configuration to one that implements the interference mitigation technique could require a short amount of network down-time. This could pose limitations in sharing spectrum with systems that are highly mobile and operations that are not pre-planned and coordinated. Implementing and adjusting interference mitigation techniques in real-time is currently in the prototype and experimentation phase and needs continued active development.

The interference mitigation features within the Active 5G RAN are invoked through spectrum sensing. Spectrum sensing is a broad area of technology development, and while it is mature for existing use cases, it is still very much an active area of research to improve capabilities. As stated above, the 3100-3450 MHz band poses unique challenges for sensing that have not been previously encountered in spectrum sharing implementations. The sensing capability will need to sense across the entire 350 MHz range, be able to decipher many different types of signals at different power levels, and sense accurately in the presence of the 5G network emissions. Each Federal system in this band has a different sensing threshold criterion that will need to be met in order to protect operations, and the sensing capability will need to be able to decipher which signal it is sensing, the operational frequency of the Federal System, and the location of the DoD system, in order to make decisions that will adequately protect that system. Additionally, sensors will need to be able to sense multiple systems at the same time. Testing and certification will need to be completed to assess the capabilities of the sensing solution to meet the defined requirements for each system in this band.

Finally, a decision engine capable of determining the correct action based on sensing has not yet been developed. The CBRS SAS can provide a blueprint for an architectural implementation, but significant modifications will be necessary to accommodate the complexities of this band.

Overall, based on the information provided here, the Active 5G RAN COA is considered a medium level of maturity. While the individual interference mitigation features are mature, and stand-alone sensing capabilities are mature, executing these features at the scale and complexity that would be required to coexist with the large number of systems in this band requires additional research and development, prototyping, and testing.

7.4.6 5G RAN Operational Impacts

Active 5G RAN employs technology which has not been field tested in realistic, congested environments. Additionally, the operating characteristics of airborne platforms in a 5G RAN environment significantly limit the extent of spectrum sharing available to non-federal systems. Active 5G RAN introduces mutual reliance with industry which can directly impact DoD system performance and mission accomplishment. While the technical implementation of Active 5G RAN does not require DoD to implement an infrastructure-based solution, effective sharing will be contingent on coordination mechanisms (supported by applicable policy) which quickly and seamlessly protect Federal systems. These requirements are listed through the following COA evaluation factors:

Operational Coordination

DoD will require additional personnel and a way to provide immediate feedback to industry if interference mitigation measures are not operating as intended. This is an as-needed coordination mechanism. DoD requires the means to escalate performance/compliance issues to the appropriate regulatory authority in a timely and effective manner. This mechanism must restore protection to DoD systems within agreed upon timeframes. The scope of this mechanism should include protection of radars at the individual and collective levels. Effective coordination will require a platform which enables industry, DoD and other USG entities to engage in authorized information sharing. This platform should cover technical matters, policy updates, best practices and points of contact required for effective coordination.

In the event of heightened adversarial competition and crisis, non-Federal users will need to vacate the band so DoD has autonomy in the band and its systems can perform optimally to identify and respond to threats. Should this not occur, Homeland Defense will be reduced and elevate the likelihood and   consequences of a potential attack. To support such a contingency, a policy with regulatory authorities   needs to be developed to provide a dynamic framework for spectrum sharing decisions when the threat level and risk increase. Mechanisms will also be needed to enable communication with non-Federal users.

Manpower and Training

MILDEPS will need to adjust existing training and evaluation programs to ensure that DoD system operators are able to operate in the 5G RAN environment. DoD may be required to update the training curriculum of operators and supervisors. If DoD is required to develop new systems to accommodate spectrum sharing the impact to training may significantly increase.

System Impacts

Based on assumptions and implementation of recommended coordination, manpower, training, readiness, and security requirements, the system performance is expected to remain unchanged. System testing will be needed before and during implementation to confirm no impacts to mission capability and to inform Active 5G RAN implementation.

Readiness

MILDEPS will require additional personnel and a mechanism to assess the performance of Active 5G RAN and any impacts to mission performance over time. The assessment criteria should be made through an interagency/industry process and support DoD mission requirements. This assessment will allow DoD to develop internal standards assess its mission readiness in the Active 5G RAN environment, develop best practices, and inform recommendations to industry and drive development to cover performance shortfalls and emergent requirements. Assessment and readiness will play an important role in driving long-term sharing policy and modernization decisions.

Security

The Active 5G RAN COA will require DoD to share information regarding sensitive systems that support national defense and contingency operations domestically and abroad for design and development of active 5G RAN spectrum sharing solutions. The potential collection of data by non-Federal systems could lead to compromise of sensitive technical and operational information, which could be used by potential adversaries to develop counter-electromagnetic capabilities (e.g., jamming) and identify US Homeland Defense vulnerabilities. It is essential to US national security that sensitive information and OPSEC be protected through obfuscation or some other means to ensure only unclassified information is shared to support sensing by non-Federal emitters employing mitigation measures in the Active 5G RAN COA. The aggregation of system information with routine spectrum sharing also presents a degree of risk to OPSEC, especially when paired with an adversary's other intelligence collection and analysis.

Active 5G RAN Programmatic Evaluation

Implemented alone, the following would be the impact of Active 5G RAN as a mitigation strategy in 3100-3450 MHz:

- **Hardware/Software Cost Impacts:**
    - In a sharing environment commercial availability of the spectrum will be limited by the ongoing necessity of mission-critical airborne systems.
    - To achieve comparable capability of systems as required by statute, cost reimbursement from the SRF would be required following a potential auction, as part of an approved Transition Plan.

- **Training Impacts:**
    - There will be significant training impacts to sharing considerations for the airborne systems. Additionally, there will be costs associated with updating training/TTPs for system operators to understand the crowded environment and be able to recognize interference, report and coordinate mitigation measures.

- **Organization Infrastructure:**
    - There may be a requirement for the DoD CIO to coordinate at an interagency level to accomplish policy and timely operational coordination measures.

- **Schedule impacts:**
    - More detailed schedule impacts will need to be developed by the military services as part of the implementation plan. Additionally, DoD will need to conduct operational tests to certify that capabilities are protected.

7.4.7 Active 5G RAN Summary

This section includes a summary, shown in **Table 7.5** below, of the evaluation factors for the Active 5G RAN COA.

TABLE 7.5: ACTIVE 5G RAN SUMMARY

Assessment Area	Factor	Evaluation Summary
Technical	COA Technical Results	See Figures 7.8-7.19.
	Extensibility	High level of extensibility because of the control over the RAN interference mitigation features and anticipated evolution and refinement of these features over time.
	Maturity	Medium level of maturity. While the individual interference mitigation features are mature and available in commercial products, and stand-alone sensing capabilities are mature, executing these features at the scale and complexity that would be required to coexist with the large number of systems in this band requires additional research and development, prototyping, and testing.
Operational	Operational Coordination	Due to the significant impact to DoD and Federal agency systems, DoD will require additional personnel, an adequate sensing system will be required to be established and tested, and an "as

TABLE 7.5: ACTIVE 5G RAN SUMMARY		
Assessment Area	**Factor**	**Evaluation Summary**
		needed" coordination mechanism put in place supported by an information sharing forum. Significant interagency coordination, which will require additional personnel, supported by applicable policy will also be required.
	Manpower and Training	Interagency coordination may be required, supported by applicable policy.
	System Impacts	System performance is expected to remain unchanged (based on assumptions and implementation of recommended coordination, manpower, training, readiness, and security requirements)
	Readiness	Development of an assessment program will be necessary to measure effectiveness of 5G interference mitigation over time, adjust readiness standards and incorporate results into future modernization requirements.
	Security	MILDEPS will be required to incorporate Operational Security (OPSEC) into sharing technical data, classification guidance and coordination mechanisms.
Programmatic	System Replacement or Hardware/ Software Cost Impacts	Unclear due to the ongoing necessity of critical airborne missions in the band.
	Training Impacts	Unclear/TBD
	Organization Infrastructure	There may be a requirement to establish/expand a DoD CIO organization to coordinate at an interagency level to accomplish timely policy and operational coordination measures.
	Schedule	Unclear due to the ongoing necessity of critical airborne missions in the band.

Table 7.5: Active 5G RAN Summary

7.4.8 COA 1 5G RAN Key Takeaways

The advanced interference mitigation features investigated through the Active 5G Radio Access Network (RAN) Course of Action (COA) will improve efficiency and effectiveness of the spectrum use.

Technical

- PRB blanking, beam muting and null steering techniques greatly improve spectrum sharing between USG and 5G commercial systems. This allows a greater spectrum sharing benefit (i.e., more spectrum to be used simultaneously by the 5G network while operating co-channel within the vicinity of USG radar systems), as compared to the baseline analysis with no Active 5G RAN interference mitigation techniques implemented.

- Most scenarios analyzed show that the interference mitigation techniques enabled within the Active 5G RAN COA do not provide sufficient interference mitigation to protect USG radar operations alone. In those scenarios, 5G sectors near USG systems will need to be turned off completely to protect USG operations.

Operational

- Spectrum sharing is contingent on establishing interagency coordination mechanisms, making adjustments to training, revising readiness assessment and OPSEC. Coordination mechanisms will require additional personnel.

Programmatic

- Requires coordination at an interagency level to accomplish timely policy and operational coordination measures.

7.5 COA 2: Dynamic Spectrum Management System (DSMS)

7.5.1 Dynamic Spectrum Management System (DSMS) COA Description

TABLE 7.6: DYNAMIC SPECTRUM MANAGEMENT SYSTEM (DSMS) COA DESCRIPTION

COA	Name	Short Description	Access to Band	Responsibility for Implementation
2	Dynamic Spectrum Management System (DSMS)	This COA enables frequency sharing through a centralized coordination system, similar to a Spectrum Access System (SAS) as used in the Citizens Broadband Radio Service (CBRS) or Automated Frequency Coordination (AFC) systems. DSMS can direct 5G base stations to temporarily curtail operation to protect the Federal system or mission and resume normal operation when the potential for interference to the Federal system or mission is no longer present.	Federal is primary and Non-Federal uses are secondary consistent with current U.S. policy positions	Shared responsibility

Table 7.6: Dynamic Spectrum Management System (DSMS) COA Description

The Dynamic Spectrum Management System (DSMS) COA was defined by the PATHSS Task Group, with the general characteristics that would guide analysis of this COA described in the quad chart approved on May 11, 2022. The quad chart is included in **Figure 7.20** below. The following sections provide a general description of the COA used as the basis for the analysis. All design, architecture, and implementation details are out of scope of this feasibility assessment.

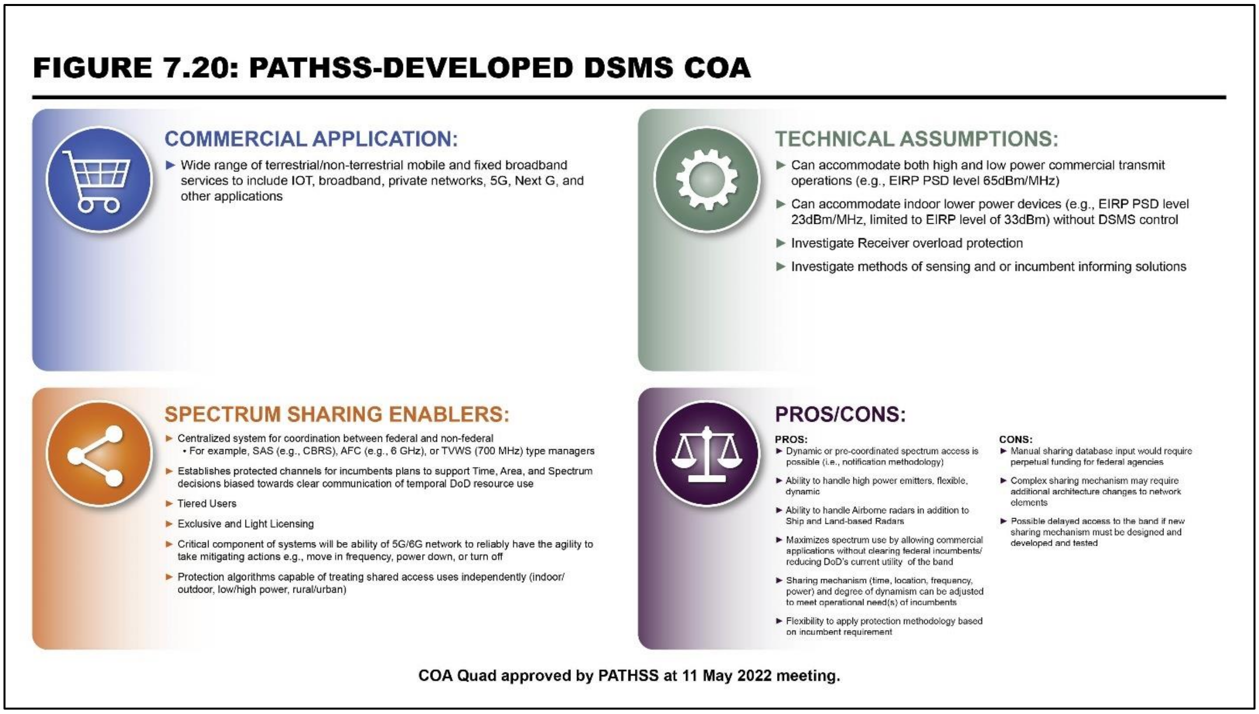

Figure 7.20: PATHSS-Developed DSMS COA

The DSMS functions as a centralized system for coordination between Federal and non-Federal users. The DSMS knows the presence of a Federal system in the area, either through sensing of the electromagnetic spectrum environment or a notification from the Federal user/system that it is operating in the area, or by receiving the information about the operational characteristics of Federal Systems from a semi-static database. The DSMS has awareness of the 5G network deployment details, and through this full situational awareness, the DSMS can direct the 5G base station operation to protect the Federal system, then resume normal operation when the potential for interference to the Federal system passes. The DSMS can manage many different types of 5G nodes, including high power, low power, and indoor use, and could be implemented to accommodate a variety of regulatory schemes.

The concept for how a DSMS would operate is similar to a SAS in the 3550-3700 MHz CBRS band or AFC in the 5925-7125 MHz band.[73]

A diagram of how this COA could be implemented is shown in **Figure 7.21** below.

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[73] Wireless Innovation Forum, *Requirements for Commercial Operation in the U.S. 3550-3700 MHz Citizens Broadband Radio Service Band*, WINNF-TS-0112 (December 12, 2022), https://winnf.memberclicks.net/assets/CBRS/WINNF-TS-0112.pdf. Note that CBRS deployment in 3550-3700 MHz band could be considered as a good example of such practice, which can be enhanced to facilitate more efficient sharing.

[redacted]

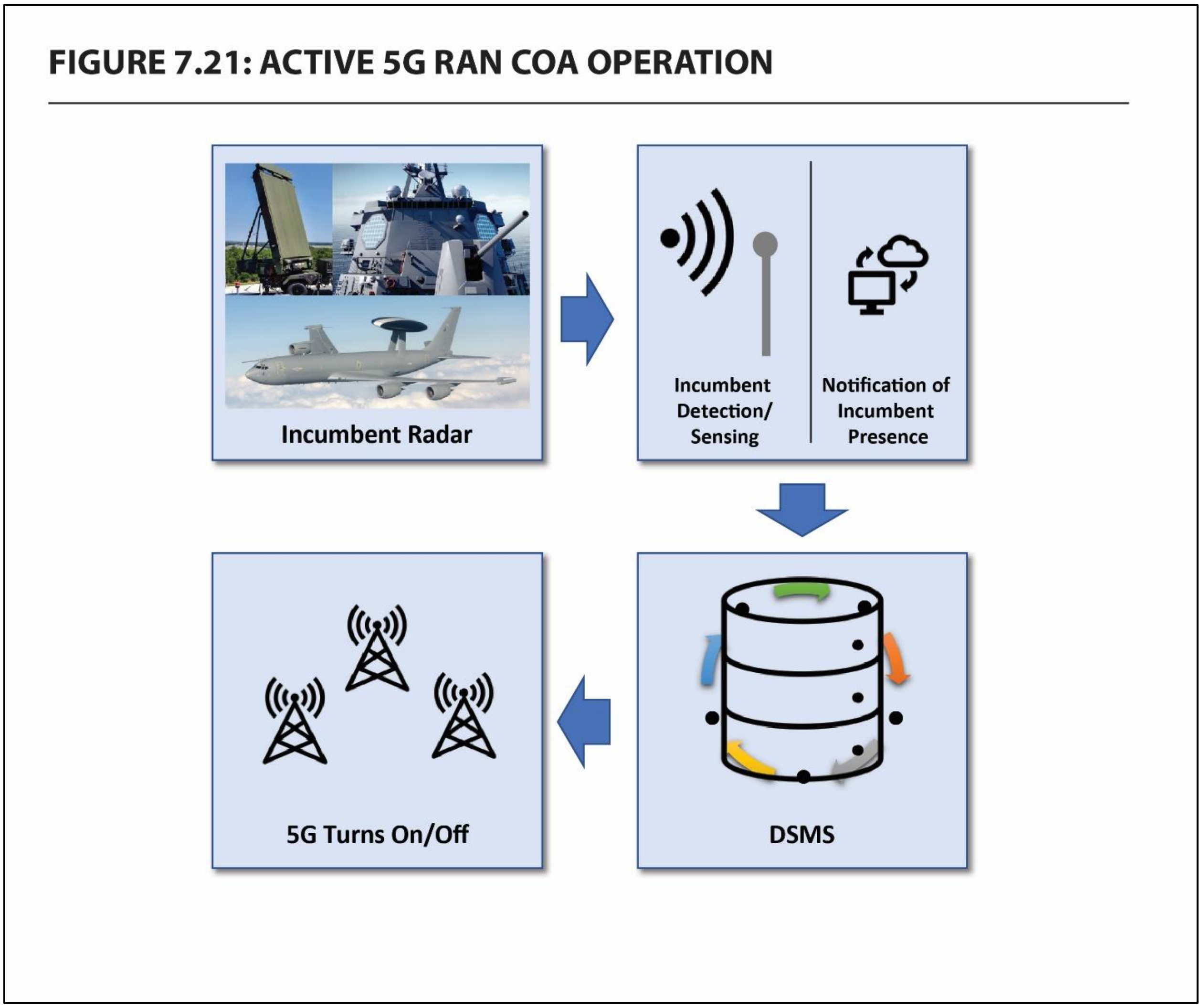

Figure 7.21: DSMS Operation

Federal Detection/Sensing

The first method to identify the presence of a Federal radar system in the band is through Federal detection or sensing. The accuracy and reliability of detecting Federal radar emissions in the 3100-3450 MHz band are critical to optimizing DSMS decisions and protecting the Federal radar missions, and thus sensing solutions will need to be carefully engineered to detect radar emissions at a defined range and accuracy. Estimated parameters could include radar pulse width/bandwidth, duty cycle, repetition time and rate, and angle of arrival, all subject to operational security assessment and further analysis.

Because COA 2 contemplates the combination of sensing and a database, a sensing solution could be integrated within the 5G base station or could be deployed as an external sensing network. An external sensing network, known as an ESC, has been implemented in the CBRS 3550-3700 MHz band, and provides a reference for how an external sensing capability could be employed within this band. Because of the wide variety of radar systems operating in the 3100-

[redacted]

3450 MHz band, the sensing capability would need to be able to sense radars with many different operating characteristics.

Federal Notification

The second method to identify the presence of a Federal radar system in the band is through a notification by the Federal system. In this case, the Federal users would inform a centralized repository of their operations in the band or their spectrum needs. This could be pre-scheduled or populated in real-time. [redacted]

Dynamic Spectrum Management System (DSMS) Operation

The information about Federal system presence, whether sensing information or Federal notification, is passed to the DSMS. It is possible that the DSMS would receive information both from sensing and notifications and combine the information for a comprehensive view of the Federal spectrum use. The information is processed by the DSMS analysis engine, which will determine how to achieve the necessary interference mitigation. The method by which the DSMS determines 5G base station operation is dependent on the final implementation and can be optimized over a number of variables (e.g,, geographic area, population, number of base stations) depending on the priorities of the 5G network provider.

The interference mitigation technique analyzed in association with this COA is cessation of 5G base station operation. A DSMS could also direct any of the interference mitigation techniques (Null Steering, PRB Blanking and Beam Muting) as described in the Active 5G RAN COA, which could reduce Federal system impact on 5G operations.[74]

7.5.2 COA 2 - DSMS Technical Evaluation

COA 2 is envisioned to be a centralized system for coordination between Federal and non-Federal users, similar to the SAS in the CBRS band or the AFC System being deployed in 6 GHz.

Modeling Approach

In the COA 2 analysis, it is assumed that the DSMS has accurate information about the electromagnetic environment, the RF characteristics of the systems in the band, the operational configuration, and time domain usage information at its disposal to manage spectrum access. This allows the DSMS to implement a variety of algorithms that can optimize any variable within the database. In the COA 2 analysis, the selected algorithm implements the received power culling method, which seeks to minimize the number of base stations required to vacate the occupied frequencies. This algorithm is similar, if not identical, to the optimization that is used when evaluating coordination requests in other shared bands such as CBRS, AWS-3, or

[74] *See supra* **Section 7.4** COA 1: Active 5G Radio Access Network (RAN).

AMBIT. Alternative culling algorithms may also improve spectrum sharing and can be implemented beyond this feasibility analysis.

All other model elements are identical to the baseline analysis approach, where base stations are either operating normally or required to vacate. In light of the temporal usage information envisioned to be contained in the DSMS, when the USG radar is not operating, all 5G base stations may resume normal operations.

Assumptions

Multiple assumptions were made in the setup and execution of the COA 2 analysis and are summarized below:

1. The DSMS has accurate information (all information available to the model) about the RF characteristics of the systems in the band, the operational configuration, and the time domain usage information at its disposal to manage spectrum access while ensuring no harmful interference to USG radars. (COA 2 Only)

2. The DSMS is the authoritative resource for determining acceptable operation of 5G base stations. (COA 2 Only)

3. This analysis implements the received power culling algorithm, by turning off base stations (full power down) until the aggregate received power at each pointing angle is below the interference threshold. (COA 2 Only)

4. Base stations that are not turned off are permitted to operate normally. (COA 2 Only)

5. One-way analysis modeling interference from 5G transmitters into USG radar receivers.

[redacted]

[redacted]

[redacted]

Technical Results

The following Priority systems in Figures 7.22-7.27 are histograms that represent the base stations turned off for Baseline vs COA 2. For the full results of all systems, see **Appendix C**. The USG systems chosen to be represented in the following figures are the scenarios that produced the largest baseline geographic separation distance for that specific USG system along with their respective COA 2 results.

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The combination of a sensing system and a database into DSMS creates a coordination framework that achieves a significant reduction in geographic separation distance required to protect Federal ground based and shipborne radar systems from interference from a mature 5G deployment. Moreover, when compared to the nearly 40,000 base stations that would be impacted by high-powered airborne operation under COA 1, the impact of airborne systems on 5G systems operating under COA 2's database-driven model is reduced by more than 50%. As noted above, the impact of COA 2 systems on government incumbent system could be further reduced through the interference mitigation techniques details in COA 1 (Null Steering, PRB Blanking and Beam Muting).

The primary benefit of COA 2 – the low number of base stations required to vacate the band to protect the Federal radar from interference – is primarily driven by the improved situational awareness provided by the DSMS. For instance, using better data combined with the highest power-culling algorithm (which allows 5G operators to choose to shut down higher power stations that are further away from the Federal systems, lowering overall system emissions) 5G operators will actually be able to retain operation within the baseline geographic separation distance.

[redacted]

7.5.3 DSMS Extensibility

Extensibility is assessed as the ability for the COA to address future Federal needs, including new systems or operational areas, as well as the evolution of commercial networks (e.g. Next G) and associated use cases. A COA implementation that offers the most flexibility will offer the greatest ability to adapt and accommodate new spectrum sharing scenarios as the wireless ecosystem evolves and spectrum sharing requirements change over time.

The interference mitigation feature utilized in the DSMS COA is to cease operation at a 5G base station to avoid interference with the Federal system. Any Federal system can be completely protected by turning off 5G base stations, so this COA is highly extensible to accommodate new spectrum sharing scenarios. As the spectrum sharing scenario increases in complexity, the granularity of a solution that only accommodates turning off 5G base stations will become less efficient in terms of overall spectrum utilization, and implementing spectrum management techniques such as those identified in the Active 5G RAN COA will allow for greater optimization of spectral resources. It can also direct any of the interference mitigation features in the Active 5G RAN COA at which point the discussion points associated with the Active 5G RAN COA Extensibility would also apply to DSMS implementation.

Overall, the DSMS COA is considered to have a high level of extensibility because of the general ability to turn off/on 5G base stations to avoid interference and anticipated evolution and refinement of Active 5G RAN interference mitigation features over time.

7.5.4 DSMS Maturity

Maturity is assessed as the developmental state of the foundational technology necessary to implement and field the COA. A COA implementation that is based on proven technology that has gone through the development process, including testing and field trials (or been previously fielded), is considered at a higher maturity than a technology that is still in the prototype or experimental stages.

The DSMS functionality of taking information (sensed or reported through a notification) about Federal system operations in the band, reasoning against that information, and instructing 5G base stations to turn on or turn off is considered mature. It is a similar functionality to a SAS, which is fielded nationally to manage spectrum access in the CBRS band. While the CBRS SAS can provide a blueprint for an architectural implementation, evolution of the system will be necessary to accommodate the complexities of this band.

The DSMS COA describes two methods for the DSMS to understand the operations in the electromagnetic operating environment. The first is through spectrum sensing. Spectrum sensing is a broad area of technology development and is mature for existing use cases but is still very much an active area of research to improve capabilities in complex electromagnetic environments. Sensing through the ESC has been deployed widely in the CBRS band to inform spectrum sharing. The 3100-3450 MHz band poses unique challenges for sensing that have not been previously encountered in spectrum sharing implementations and will require additional research and development. The sensing capability will need to sense across the entire 350 MHz

[redacted]

range, be able to decipher many different types of signals at different power levels, and sense accurately in the presence of the 5G network emissions. Each Federal system in this band has a different sensing threshold that will need to be met to protect operations, and the sensing capability will need to be able to decipher which signal it is sensing to make decisions that will adequately protect that system. Additionally, sensors will need to be able to sense multiple systems at the same time. Testing and certification will need to be completed to assess the capabilities of the sensing solution to meet the defined requirements for each system in this band.

The second method for the DSMS to understand the operations in the electromagnetic operating environment is through a notification that a Federal system is present. [redacted] Such a system could alleviate the necessity for an extensive, nationwide passive sensing system to accommodate airborne systems and missions.

Overall, the DSMS COA is considered a medium level of maturity. While the DSMS concept is at a high level of maturity due to its similarity to the CBRS SAS, the decision engine is considerably more complex, and the means to inform the DSMS of spectrum use (spectrum sensing or Federal notification) need additional research and development to operate in the complex spectrum environment of the 3100-3450 MHz band.

7.5.5 DSMS Operational Impacts

Federal

DSMS employs technology which has not been field tested in realistic, congested environments. As in all COAs considered in this report, the operating characteristics of airborne platforms will significantly limit the geographic availability of spectrum for 5G uses. Like Active 5G RAN, effective spectrum sharing will be contingent on interagency coordination mechanisms which quickly and seamlessly protect Federal systems across a variety of conditions. These requirements are listed through the following COA evaluation factors:

Operational Coordination Measures

To be effective, DSMS must be the authoritative source of spectrum availability in the band. DoD will require an authorized method for industry base stations to schedule operations to protect Federal systems and gain assurance that industry protection measures are effective. DoD will require time sensitive- compliance by industry and an ability for DoD to escalate compliance

[redacted]

issues.[75] This mechanism requires that the appropriate authority will restore protection to DoD systems within an agreed time frame. The scope of this mechanism should cover protection of systems at the individual and collective levels. DoD may be required to establish an operational coordination capability which can interface with other Federal and industry partners to coordinate scheduling activities and resolve compliance matters. For policy and operational management, additional analysis would be needed during implementation planning. DoD will require a mechanism which enables industry, DoD and other USG entities to engage in authorized information sharing. This platform should cover technical matters, policy updates, best practices, and points of contact required for effective coordination.

Manpower and Training Requirements

MILDEPS will need to adjust existing training and evaluation programs to ensure that DoD system operators and supervisors can operate DoD systems in the DSMS environment and support coordination mechanisms and platforms. Training standards will need to be coordinated with industry and harmonized through the appropriate USG authority, according to agreed DoD/industry standards. If DoD is required to develop new systems to accommodate spectrum sharing, the impact to training may significantly increase.

System Impacts

Based on assumptions and implementation of recommended coordination, manpower, training, readiness, and security requirements, system performance is expected to remain unchanged. System testing will be needed before and during implementation to confirm no impacts to mission capability and to inform DSMS implementation.

Readiness

MILDEPS will be required to assess the performance of DSMS and any impacts to mission performance over time. The assessment criteria should be developed through an interagency/industry process and support DoD mission requirements. This assessment will allow DoD to develop internal standards to assess its mission readiness in the DSMS environment, develop best practices, and inform recommendations to industry and drive development to cover performance shortfalls and emergent requirements. Assessment and readiness will play an important role in driving long-term sharing policy and modernization decisions.

Security

The DSMS COA will require DoD to compile information regarding time, location, and spectrum use for sensitive systems that support defense and contingency operations, both

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[75] Wireless Innovation Forum, *Requirements for Commercial Operation in the U.S. 3550-3700 MHz Citizens Broadband Radio Service Band*, WINNF-TS-0112 (December 12, 2022), https://winnf.memberclicks.net/assets/CBRS/WINNF-TS-0112.pdf. (*Note*, CBRS deployment in 3550-3700 MHz band could be considered as a good example of such practice, which can be enhanced to facilitate more efficient sharing).

[redacted]

domestically and abroad. If this data is exposed, it presents a new avenue for adversarial exploitation. For test ranges, this is an operational cue that something of potential intelligence interest is planned to occur on these days. As previously mentioned, this information cannot be compromised without significant impacts to OPSEC. To mitigate these impacts to information protection, DoD must maintain control of the sensitive information about DoD spectrum use in the DSMS COA and incorporate a robust cyber defense to protect it. The current CBRS solution addresses similar challenges with a scheduling portal where mission information is kept in a secure Level 5 [redacted] DOD-only access portal, and very limited details of the spectrum usage are provided to the commercial SAS coordinators. This would need to be paralleled in any new COA 2 EMBRSS effort, or simply moved to a secure SIPRnet environment. While aggregation of system and operational data in one location (e.g., cloud) creates a vulnerability, it allows DoD to retain control of sensitive information. The spectrum sensing capability employed in DSMS presents a level of risk similar to that of Active 5G RAN. Each system has a different sensing threshold that must be met to protect classified information and OPSEC. Overall, any method of sharing poses risk as shared spectrum occupants – especially adversaries – could analyze combined system and operational information to reveal gaps and vulnerabilities.

7.5.6 DSMS Programmatic Evaluation

- **Hardware/Software Cost Impacts:**
  - DoD will need to develop, test, deploy, and maintain the DSMS capability, incurring significant cost to the Department. Airborne systems will continue to operate in this sharing environment on an ongoing basis through a robust, secure coordination framework. Modifying existing DoD systems and ensuring comparable capability of systems as required by statute would necessitate cost reimbursement from the SRF following a potential auction and as part of an approved Transition Plan.

- **Training Impacts:**
  - There will be significant training requirements associated with updating training/TTPs for DoD system operators to notify the DSMS of spectrum usage requirements, as well as understand the crowded environment and be able to plan for and report operations in spectrum, recognize interference, report, and coordinate mitigation measures through the DoD.

- **Organization Infrastructure:**
  - The policy and operations management organization required for this COA will require significant DoD organizational infrastructure along with secure hardware/software/cloud-based reporting and monitoring systems that have not yet been developed. There will be a significant impact on schedule as the system is developed, tested and fielded. This will also require significant interagency coordination and regulatory compliance reporting.

- **Schedule impacts:**
  - Implementing a nationwide DSMS system will take significant testing. The schedule will also be impacted by establishing the DoD policy and operational management

organization and will require significant inter-agency coordination and policy development.

7.5.7 DSMS Summary

This section includes a summary, shown in **Table 7.7** below, of the evaluation factors for the DSMS COA.

TABLE 7.7: EVALUATION FACTORS FOR THE DSMS COA

Assessment Area	Factor	Evaluation Summary
Technical	COA Technical Results	See Figures 7.22-7.27.
	Extensibility	High level of extensibility because of the general ability to turn off/on 5G base stations to avoid interference, and anticipated evolution and refinement of Active 5G RAN interference mitigation features over time.
	Maturity	Medium level of maturity. While the DSMS itself is at a high level of maturity due to its similarity to the CBRS SAS, the means to inform the DSMS of spectrum use (spectrum sensing or Federal notification) need additional research and development to operate in the complex spectrum environment of the 3100-3450 MHz band.
Operational	Operational Coordination	DoD takes responsibly for all scheduling and coordination of DoD operations with the DSMS. DoD will require time sensitive compliance by industry and an ability to escalate compliance issues through the appropriate processes. DoD may be required to establish a coordination capability which can interface with the DSMS.
	Manpower and Training	DoD required to incorporate notification to the DSMS into existing training programs. Interagency coordination may be required, supported by applicable policy and additional personnel.
	System Impacts	System performance is expected to remain unchanged (Based on assumptions and

TABLE 7.7: EVALUATION FACTORS FOR THE DSMS COA		
Assessment Area	**Factor**	**Evaluation Summary**
		implementation of recommended coordination, manpower, training, readiness, and security requirements)
	Readiness	Requirements include development of an assessment program to assess effectiveness of DSMS over time, adjust readiness standards and incorporate results into future modernization requirements.
	Security	Requirement to incorporate OPSEC into sharing technical data, classification guidance and coordination mechanisms. Based on the expected volume and extent of sharing, considerable study will be required to guide implementation, especially for airborne Federal systems.
Programmatic	System Replacement or Hardware/ Software Cost Impacts	Significant system development costs associated with the evolution of the CBRS SAS and ESC systems to accommodate the more complicated spectrum environment at 3100-3450 MHz.
	Training Impacts	Significant training for other DoD systems to operate within the DSMS system.
	Organization Infrastructure	Requires DoD policy and operations management organizations and supporting infrastructure.
	Schedule	A nationwide DSMS system will take significant testing. The schedule will also be impacted by establishing the DoD policy and operational management organization and to field sensors. Will require significant inter-agency coordination and policy development.

Table 7.7: Evaluation Factors for the DSMS COA

7.5.8 COA 2 DSMS - Key Takeaways

A dynamic spectrum management system (DSMS) that evolves the implementation of Citizens Broadband Radio Service (CBRS) in the 3550-3700 MHz band, presents a feasible spectrum sharing framework between the Federal USG systems and commercial systems in the band. While the creation of a coordination framework based on a DSMS would make sharing feasible, commercial availability of the spectrum will continue to be impacted by critical airborne systems in the band that will trigger additional spectrum access limitations.

Technical

Implementing a DSMS capability that uses current information about 5G deployment and USG operations to optimize real-time decisions about the number of 5G sectors that must be turned off makes spectrum sharing feasible.

Operational

Spectrum sharing is contingent on establishing coordination mechanisms, making adjustments to training, revising readiness assessment and OPSEC. The DSMS COA may increase operational requirements to support spectrum sharing if a notification architecture is implemented.

Programmatic

Requires robust DoD policy and operations management organizations and supporting infrastructure and additional personnel.

7.6 COA 3 RADAR 3GPP Digital Interference Cancellation

TABLE 7.8: COA 3 RADAR 3GPP DIGITAL INTERFERENCE CANCELLATION				
COA	**Name**	**Short Description**	**Access to Band**	**Responsibility for Implementation**
3	RADAR Third Generation Partnership Project (3GPP) Digital Interference Cancellation	This COA enables frequency sharing through the use of a programmable 3GPP signal digital canceller on the DoD RADAR receiver.	Federal is primary and Non-Federal uses are secondary consistent with current U.S. policy positions	Federal

Table 7.8: COA 3 RADAR 3GPP Digital Interference Cancellation

The Radar 3GPP Digital Interference Cancellation COA was defined by the PATHSS TG, with the general characteristics that would guide analysis of this COA described in the quad chart approved on May 11, 2022, included in **Figure 7.28** below. The following sections provide a general description of the COA. All design, architecture, and implementation details are out of scope of this feasibility assessment.

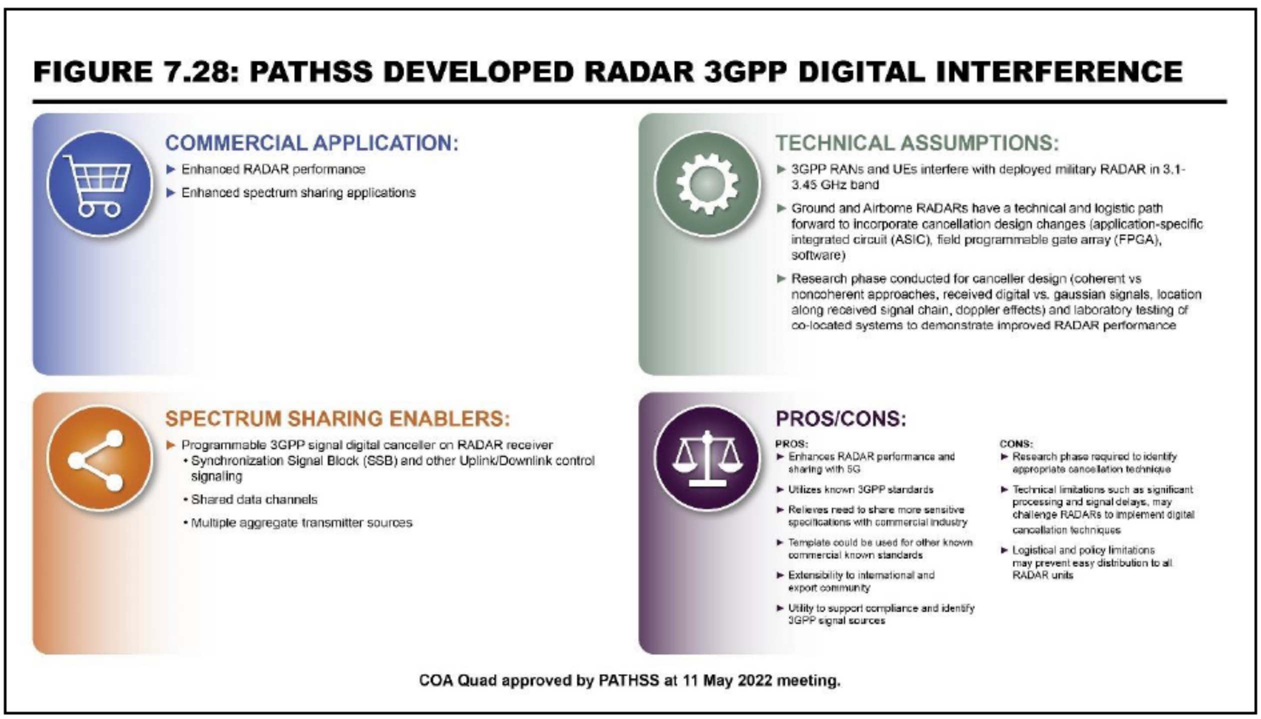

Figure 7.28: PATHSS Developed RADAR 3GPP Digital Interference Cancelation COA

7.6.1 RADAR 3GPP Digital Interference Cancellation Description

This COA proposed to modify the signal processing chain of existing and future Federal systems to digitally cancel 5G interference signals. While such digital cancellation would occur "in software," it was noted that hardware changes would also be required to implement this COA, such as the use of application-specific integrated circuits (ASICs) and field programmable gate arrays (FPGAs) that might not be part of the existing radar design. For legacy Federal systems, these modifications would represent significant retrofit and integration requirements necessary to maintain performance comparable to current levels. For future systems, they would represent additional spectrum coexistence requirements specific to radars operating in 3100-3450 MHz.

Interference cancellation is a set of signal processing techniques for mitigating interference and noise into a receiver. The feasibility of using interference cancellation to enable greater spectrum sharing depends on multiple factors, such as the structure of the desired and interfering signals, the geometry of the interaction, and information sharing between the USG System and interfering networks. This COA proposes to utilize the 3rd Generation Partnership Project (3GPP) 5G NR standard as a basis for interference cancellation. This would allow the canceller to identify and leverage the most distinct signals defined in the standard, such as the signals associated with the synchronization signal block (SSB) and other uplink or downlink control signaling. Interference cancellation is also a technique used to combat against intentional interference in electromagnetic warfare, and some DoD radars have developed capabilities along these lines. However, if interference is present from 5G, this lessens the DoD radar's effectiveness against adversaries' electromagnetic attacks, such as jamming and deception. For some of these DoD systems that need interference cancellation for these types of aggressive radio frequency signals, added 5G interference could be detrimental to their mission of defending the US from an attack.

7.6.2 Technical Evaluation

DoD conducted a proof-of-concept demonstration to better understand the level of maturity and performance of interference cancellation technology. The demonstration looked at active cancellation of a 5G signal on an emulated DoD radar system. The demonstration, performed in an anechoic chamber, shows this technology is promising. Future work to further analyze potential material solutions is recommended.

The demonstration conducted to support the technical evaluation of this COA did not yield sufficient evidence to determine the amount of interference cancellation that could be achieved. Therefore, a technical analysis was not completed in the same way as for COA 1 and COA 2.

7.6.3 Extensibility

Radar 3GPP Digital Interference Cancellation technology could be applied to many of DoD's platforms based on the individual system requirements; however, 3GPP standards continue to evolve, and there is no guarantee that any chosen waveform will retain the same structure or even be retained. Therefore, interference cancellation technology must be modified and updated to incorporate new technology standards. While the report anticipates that most modifications would be software based, DoD would need to plan for ongoing maintenance and sustainment lifecycle needs. The techniques developed as part of COA 3 could be used as part of a framework defined by COA 1 and/or COA 2 to make the sharing framework more efficient, e.g. by adjusting the incumbent threshold levels or separation distances.

7.6.4 Maturity

The underlying technology has been demonstrated in the laboratory and integrated into select systems but is still considered in the experimental and prototype phase. To achieve sufficient interference mitigation a canceller would be required to address incoming signals from a potentially large number of simultaneous interferers, both base stations (BS) and user equipment (UE). Significant engineering, integration and testing would be required to fully assess utility on a platform-by-platform basis.

7.6.5 RADAR 3GPP Digital Interference Cancellation Operational Evaluation

If DoD relied solely on noise cancellation technologies to operate within this band, the impacts of the system failing could range from lost training for military personnel to a successful attack on the United States. Many of these platforms are used as integral parts of our Homeland Defense. If these platforms failed to perform to their fullest capability, there could be extremely high consequences. Additionally, the systems that operate in this band are designed to provide enhanced situational awareness of the environment and identify potential threats. While some of the objects are known and may be identified by the system, there may be objects that the radar cannot identify. If those objects were not identified because the noise cancelling system had interpreted them as noise, then the system's operations would be compromised.

Operational Coordination Measures

Because Digital Interference Cancellation capable of sufficiently protecting sensitive radars is an emergent technology, the full scope of coordination is undetermined. Moderate interagency coordination will be required to ensure DoD equities are preserved as this technology evolves. An information sharing platform to facilitate coordination may be required.

Manpower and Training

DoD will need to support an effort to sustain and maintain new systems and operator proficiency as it introduces a new aspect to the overall training environment. [redacted]

System Impacts

If DoD relied solely on noise cancellation technologies to enable coexistence within this band, each platform's electromagnetic spectrum survivability requirements would have to be reassessed to ensure that the noise cancellation technology met required electromagnetic interference and compatibility parameters to maintain electromagnetic spectrum superiority. This will require an extremely high level of time, effort, and resource commitment to continue to validate and test developing technology, then modernize over 100 unique DoD systems.

Readiness

MILDEPS will require a mechanism to assess the performance of Radar 3GPP Digital Interference Cancellation technology and any impacts to the primary mission of military spectrum users over time. This assessment will allow DoD to develop internal standards that assess its mission readiness while using interference mitigation technologies, develop best practices, and inform recommendations to industry and drive development to cover performance shortfalls and emergent requirements. This assessment will also allow commercial licensees and other types of authorized users to determine the utility of the spectrum to their operations.

Security

The 3GPP COA provides DoD systems with the greatest level of information and operational security among the COAs. The benefits of Radar 3GPP Digital Interference Cancellation technology are increased electromagnetic spectrum survivability capability to continue to operate in both congested and contested electromagnetic spectrum operations environments. There is a high level of ability to secure sensitive information because DoD technical data and operational information are not shared with non-Federal users.

7.6.6 RADAR 3GPP Digital Interference Cancellation Programmatic Evaluation

- **System Replacement or Hardware/ Software Cost Impacts:**
  - Since there is no off-the-shelf solution, the report is not able to assess the true cost to implement this technology. A conservative cost estimate for each system would include non-recurring engineering, testing and integration cost per individual platform in addition to the per-unit cost. Additional lifecycle costs, including bench stock and spares, test equipment, and training for technicians will also have to be considered. Additionally, a sustained modernization effort may be required as commercial systems and associated waveforms evolve over time.
  - [redacted]

- **Training Impacts:**

- There will be significant training requirements for each individual system replacement and/or hardware/software upgrades.

- **Organization Infrastructure:**
  - Any organizational infrastructure impacts will need to be addressed during implementation.

- **Schedule impacts:**
  - Anticipate 15-20 years or longer to implement this COA in order to develop, test, and field new systems and/or hardware/software upgrades to all DoD systems. Fully fielding this technology would be dictated by each Service and the Program Office responsible for maintaining & sustaining the systems.

7.6.7 RADAR 3GPP Digital Interference Cancellation COA Summary:

This section includes a summary, shown in Table 7.9 below, of the evaluation factors for the 3GPP COA.

TABLE 7.9: EVALUATION FACTORS FOR THE 3GPP COA

Assessment Area	Factor	Evaluation Summary
Technical	COA Technical Results	Impact on baseline technical results not analyzed due to low maturity of technology.
	Extensibility	Low Extensibility. Cancelers are specific to the commercial waveform and would require software/hardware modifications to be tailored to other waveforms or spectrum bands.
	Maturity	Low Maturity. Experimental phases, and limited implementation in an operational environment. To achieve sufficient interference mitigation a canceller would be required to address incoming signals from a potentially large number of simultaneous interferers, which has not been demonstrated.
Operational	Operational Coordination	A coordination mechanism between DoD, the appropriate regulatory authority and industry partners to address the performance of this COA would be required. Moderate interagency coordination would be required to ensure DoD equities are preserved as this technology evolves.

TABLE 7.9: EVALUATION FACTORS FOR THE 3GPP COA		
Assessment Area	**Factor**	**Evaluation Summary**
	Manpower and Training	No foreseen changes to current methods/effort to sustain and maintain new systems and operator proficiency
	System Impacts	The COA would require extremely high levels of time, effort, and resource commitment to continue to validate and test developing technology, then modernize over 100 DoD systems.
	Readiness	Requirements include development of an assessment program to measure effectiveness of this COA over time, adjust readiness standards and incorporate results into future modernization requirements.
	Security	No anticipated changes to current DoD OPSEC procedures
Programmatic	System Replacement or Hardware/ Software Cost Impacts	[redacted]
	Training Impacts	Significant training requirements for each individual system replacement and/or hardware/software upgrades.
	Infrastructure	Any organizational infrastructure impacts will need to be addressed during implementation.

TABLE 7.9: EVALUATION FACTORS FOR THE 3GPP COA		
Assessment Area	**Factor**	**Evaluation Summary**
	Schedule	Anticipate 15-20 years or longer to implement this COA in order to develop, test, field new systems and/or hardware/software upgrades to all DoD systems. Full schedule impacts will be identified during implementation by each Service and the Program Office responsible for maintaining & sustaining the system/platform.

Table 7.9: Evaluation Factors for the 3GPP COA

7.6.8 COA 3 RADAR 3GPP Digital Interference Cancellation Key Takeaways

Radar 3GPP Digital Interference Cancellation is not a feasible solution for sharing.

Technical

- Radar 3GPP Digital Interference Cancellation technology is not mature and is waveform dependent.
- To achieve sufficient interference mitigation a canceller would be required to address incoming signals from a potentially large number of simultaneous interferers, which has not been demonstrated.

Operational

- Presents robust integration requirements and significant operational impact due to downtime of systems to integrate interference cancellation technology.
- Significant training requirements due to numerous system updates/upgrades.

Programmatic

- Integrating new capabilities on every system would require a full DoD Doctrine, Organization, Training, Materiel, Leadership, Personnel, Facilities and Policy (DOTMLPF-P) review.

7.7 Strategic and Operational Overview

[redacted]

As discussed throughout this report, and particularly in **Chapter 4**, the 3100-3450 MHz band is critical to the DoD operations, especially in light of current and emerging threats. This was reemphasized in a 2023 Senate Armed Services Committee hearing, during which General Glen VanHerck, commander of U.S. Northern Command and the North American Aerospace Defense Command testified: “The PRC and Russia have fielded cruise missiles, delivery platforms, and non-kinetic capabilities to hold at risk critical infrastructure of military and civilian in the United States and Canada. Those capabilities allow them to strike with limited warning and significant consequences.”[76] With respect to spectrum sharing, General VanHerck further stated, “I am concerned about the potential national security impacts of auctioning or selling off that spectrum. It’s my assessment there will be impacts, as you pointed, out to our domain awareness capabilities.”[77]

DoD assessed the operational impacts and feasibility of spectrum sharing based on its ability to conduct Homeland Defense. The purpose of Homeland Defense is to protect against incursions or attacks on sovereign U.S. territory, the domestic population, and critical infrastructure and key resources as directed. The Department executes multiple missions in Homeland Defense operations but within this assessment the focused missions are Air and Missile Defense (AMD), Counter-Unmanned Aerial Systems (C-UAS), Space Domain Awareness, airlift, training and testing, based on analysis of 16 priority systems providing capability in these mission areas.

If non-Federal emitters are permitted to operate in the 3100-3450 MHz band, the electromagnetic operational environment (EMOE) will be more congested and constrained. Consequently, the likelihood and frequency of Electromagnetic Interference (EMI) will increase. When interference increases to the point it exceeds the Interference Protection Criteria (IPC), the system performance is degraded to the point of mission impact. Some systems and operators may be able to temporarily alter (i.e., execute Tactics, Techniques, Procedures (TTP)) their operations to mitigate the interference, while others may be affected to the point they are no longer able to routinely maintain their mission capability. When this occurs, it leaves critical vulnerabilities and gaps in strategic mission areas, from failure to identify threats to reduced ability in enabling leaders to make timely and accurate decisions. (To this end, the baseline analysis described throughout Chapter 6 addresses the required geographical separation between USG and 5G systems to allow for them to share spectrum in the EMBRSS band (3100 – 3450 MHz), assuming that no interference mitigation techniques are employed.)

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[76] U.S. Senate, Committee on Armed Services, *Hearing to Receive Testimony on the Posture of the United States Northern Command and United States Southern Command in Review of the Defense Authorization Request for Fiscal Year 2024 and the Future Years Defense Program* (testimony by Gen. Glen Vanherck), 118th Cong. 1st sess. (March 23, 2023), https://www.armed-services.senate.gov/imo/media/doc/23-16_03-23-2023.pdf.

[77] *Id*., “It is clear that our competitors possess long-range strike capabilities that could be used to attack the United States and Canada from outside the detection range of legacy sensors. Our competitors and potential adversaries have shown that they will hold the homeland at risk in a conflict. The PRC and Russia have already fielded highly advanced hypersonic capabilities.”

[redacted]

A description of impacts to DoD operations and affected mission areas are provided in the following sections.

7.7.1 Air and Missile Defense (AMD)

Air and Missile Defense (AMD) consists of direct (active and passive) defensive actions taken to destroy, nullify, or reduce the effectiveness of hostile air (including UAS) and missile threats against friendly forces and assets. Executing AMD operations requires continuous surveillance to deliver timely air and missile threat detection and warning to ensure reaction time for friendly forces to seek shelter or take offensive action. [redacted] Implementation of only one COA could reduce the occurrence of interference but it is not likely to sufficiently reduce the high mission risk to the AMD mission. This mission is often a highly dynamic one when systems are airborne, mobile, and subject to short notice changes of mission. Consequently, multiple COAs (i.e., a combination of both DSMS and Active 5G RAN) will need to be implemented to ensure critical AMD systems retain their capabilities.

7.7.2 Counter Unmanned Aerial System (C-UAS)

C-UAS is a subset of AMD which consists of direct (active and passive) defensive actions taken to destroy, nullify, or reduce the effectiveness of hostile UAS threats against friendly forces and assets. [redacted] Implementation of only a single COA could reduce the occurrence of interference but it is not likely to sufficiently reduce the high mission risk to the C-UAS mission. As with AMD, C-UAS mission will require implementation of multiple COAs (i.e., a combination of both DSMS and Active 5G RAN) to ensure C-UAS systems retain their capabilities.

7.7.3 Space Domain Awareness

[redacted]

7.7.4 Air Navigation and Airlift

Air Navigation and Airlift mission risk is high for the ability to conduct movement of personnel and materiel via air mobility forces. [redacted] Implementation of only a single COA could reduce the occurrence of interference but it is not likely to sufficiently reduce the high mission risk due to airborne operations and the large geographic area for the Air Navigation and Airlift mission. The mobile nature of Air Navigation and Airlift mission will require implementation of multiple COAs (i.e., a combination of both DSMS and Active 5G RAN) to ensure systems retain their capabilities.

7.7.5 Training

All Military Departments employ systems in this band that are essential for satisfying Homeland Defense requirements. These systems require frequency operation to support operator training and maintenance of proficiency. As a result, significant strategic, operational, and tactical advantages in combat and training would be at risk if DoD were to lose access without being able to effectively share this spectrum with non-Federal users. The operational capabilities in this band are necessary for training warfighters before they deploy overseas, in addition to protecting our homeland.

Every day of the year, our joint forces (including both active-duty and reserve components) train in all domains, both on and off federal lands. During training, units gain the proficiency to operate their weapon systems with the goal of certification to conduct successful combat operations. As the Department focuses its attention on the near-peer fight, the ability to access and maneuver within the EMS becomes critical. Specifically, the training community requires spectrum access to operate spectrum-dependent systems, Electromagnetic Attack, enable Electromagnetic Support, and replicate a contested EMS to train Electromagnetic Protection Systems. [redacted]

The 2023 National Defense Authorization Act directs the DoD to integrate EW into 14 Tier 1 and Tier 2 Joint Services training exercises between 1 October 2023 thru 30 September 2027. It specifies the Chairman of the Joint Chiefs of Staff must require both offensive and defensive EW capabilities be used, with the opposing force possessing the EW order of battle and capabilities of a potential adversary. The increased focus on EW during exercises will further congest the 3100-3450 MHz band and increase opportunities for interference with non-Federal systems.
[redacted]

Implementing operational coordination measures between DoD and non-Federal users will mitigate the risk to the training mission. Even though training is conducted daily, training is forecasted and planned months in advance, allowing time to coordinate spectrum sharing requirements and the shutdown of 5G transmitters.

7.7.6 Testing

Test operations include Federal test ranges and developmental contractor facilities for Research and Development (R&D) performance verification and training centers to validate total combat system designs and conduct engineering development, testing, and evaluation. These sites enable design and fabrication of products, monitor production, certify [redacted], integrate and test combat systems equipment and computer programs, and evaluate operational suitability. Several of these test sites make up the DoD Major Range and Test Facility Base (MRTFB) ranges. They are a multi-domain, full-spectrum, land, water, and airspace dedicated to supporting testing and evaluation (T&E), experimentation, demonstration, and training activities across the Services, Joint Force, and coalition partners. The MRTFB ranges support rapid response and traditional acquisition activities associated with performance, effectiveness, and suitability evaluations in realistic threat environments. The MRTFB ranges are designated as the core set of DoD T&E infrastructure that must be preserved as a national asset to provide the capabilities needed to support DoD acquisition. They use numerous instrumentation systems and range support capabilities that operate at many different frequencies.

[redacted]

- [redacted]
- [redacted]

[redacted]

7.7.7 Regulatory Overview

An assumption of this feasibility report is that the regulatory framework will address the coordination requirements, enforcement protocols, and security needed to enable sharing in the 3100-3450 MHz spectrum without impacting military operations. Specific expectations for the regulatory conditions that will enable sharing in the 3100-3450 MHz band include that:

- **Status**: Federal radiolocation operation will retain a primary allocation status in this frequency range with the potential development of a footnote, if needed, to ensure that "all practical steps shall be taken" to protect Federal radiolocation operations from harmful interference. (This is in line with other US footnote protections to the Table of Allocations under Section 2.106 of Title 47.)

- **Development**: The regulatory framework will accommodate current government operations and facilitate the deployment in the band of future Federal operations to accommodate anticipated growth based on mission requirements.

- Regulatory protections enacted to protect Federal users from harmful interference will apply with equal force to both current and future government operations.

- **Liability**: USG operations do not assume liability for damages to 5G hardware resulting from routine radar operations that comply with agreed upon restrictions. Under such scenarios, Federal users are not required to assume the responsibility of mitigating interference from USG operations to 5G users.

- **Data Protection**: Regulatory protections for this band will address the unique security concerns related to information transmitted to, or required from, 5G licensed wireless users as part of the employment of a coordination framework, including both sensing and notification provisions, in addition to measures that are part of base station architecture. A baseline assumption is that DoD will share information that is obfuscated in a manner that will allow it to remain unclassified and will address concerns regarding aggregation of information or will limit sharing opportunities to those organizations and companies capable of operating at the appropriate level of classification.
    - For the DSMS COA, security measures will rely as a baseline point of reference on Citizens Broadband Radio Service (CBRS) regulatory rules and architectures to inform security requirements, including the protection from unauthorized data input or alteration of stored data.
    - The CBRS model of multi-stakeholder groups developing security models for consideration, subject to FCC review, provides an important template for database forms of coordination to enable sharing in the 3450-3550 MHz spectrum band.[78] In general, regulatory frameworks must address a need for security mechanisms to be updated on an ongoing basis to reflect state-of-the-art protection against constantly evolving security threats.

- **Enforcement**: If protected USG operations receive harmful interference from 5G operations in the 3100-3450 MHz band, a licensee will, upon notification, modify its operations or technical parameters as needed to eliminate the interference. Licensees will provide and maintain a point of contact at all times so that immediate contact can be made should interference against protected USG operations occur.[79]

The regulatory framework will address novel enforcement issues that arise from the scope and scale of employing the Active 5G RAN COA, particularly in light of the complexity of Federal

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[78] Wireless Innovation Forum, *Requirements for Commercial Operation in the U.S. 3550-3700 MHz Citizens Broadband Radio Service Band*, WINNF-TS-0112 (December 12, 2022), https://winnf.memberclicks.net/assets/CBRS/WINNF-TS-0112.pdf.

[79] *See, e.g.*, "Protection of Federal Government operations," 47 C.F.R. part 27 § 1134 (2023), https://www.ecfr.gov/current/title-47/chapter-I/subchapter-B/part-27/subpart-L/subject-group-ECFRd7a35c1d44d28bb/section-27.

operations in the band. For an Active 5G RAN framework, regulatory provisions will support the elevation of performance or compliance issues to the appropriate oversight authority.

Regulatory provisions regarding enforcement also must account for the challenges of quickly identifying and responding to sources of interference, particularly for certain USG Federal operations, such as airborne capabilities. While the technical requirements of a sharing framework will be designed to prevent harmful interference, the enforcement requirements must recognize that timely action on the part of oversight authorities must be addressed as part of regulatory protections, including required discontinuance of operations in a timely manner when interference occurs. Further, the expectation is that regulatory measures will anticipate the potential implications of aggregate interference, as well as individual sources of interference, and tailor mitigation efforts to address both causes, respectively, when necessary.

- **Data Protection/Enforcement**: The expectation is that additional techniques and protocols would be implemented to address the unique enforcement concerns raised by implementation of sharing framework in this frequency range. This would include, but not be limited to, the development of security protocols that meet the standards set by the Commission in collaboration with NTIA and affected Federal stakeholders.

- **Enforcement/Emergency**: 5G wireless licensees employing the Active 5G RAN COA would be subject to requirements, as needed, to assist the Commission in performing its enforcement responsibilities, including the adoption of procedures to discontinue operations as directed by the Commission.

- **Emergency**: Aligned with the disposition of this issue in recent rulemakings, the expectation is that instead of imposing a specific provision for national emergencies, in the rare circumstances under which such operational needs may arise, such operational needs can be accommodated in the band under and consistent with section 706(c) of the Communications Act and other relevant authorities. Under section 706(c), a national emergency would be triggered by a "proclamation by the President that there exists a war or threat of war or a state of public peril or disaster or other national emergency."

7.7.8 Defense Industrial Base Regulatory Considerations

Defense Industrial Base (DIB) contractor manufacturing, integration, and sustainment facilities require access to the 3100–3450 MHz spectrum band to perform experimentation, testing, and sustainment for radars, effectors, and other systems contracted by the DoD and other Federal agencies. Typically, these facilities operate in an outdoor environment to meet the requirements of physically large operational systems. It is critical that these facilities retain access to this band to ensure federal contract requirements can be fulfilled. Furthermore, any future sharing in the band must also account for the location of these contractor facilities to address potential interference considerations.

DoD contractors must obtain frequency licenses to conduct these testing activities at their facilities. Spectrum access for DIB operators has in the past been secured by a combination of experimental licenses issued by the FCC and Radio Frequency Authorizations (RFAs) issued by NTIA. FCC experimental authorizations are an important tool for spectrum access when they can be timely secured, despite that several factors constrain the viability of this spectrum access mechanism. This outcome is in part due to the challenges of coordinating with and gaining approval from other licensed band users, which is not guaranteed because of the non-interference nature of an FCC experimental license.

As an alternative, DIB operators should work with their government program offices to obtain an RFA via NTIA for use at the contractor facilities. The process to obtain an RFA is complex and requires significant lead time. This circumstance can preclude early authority to radiate during product development and does not allow for rapid changes in operations as often are needed for developmental systems. Nonetheless, RFAs confer priority access to spectrum and are a preferred licensing mechanism for this band.

The issuance of RFAs at contractor sites is standard practice and mandated by DoD service branch regulations such as Army Regulation 5-12, Section 4-2(1). These RFAs are issued in the name of the Federal agency in support of a government contract being executed at the contractor site. As such, Federal priority would be retained regardless of whether the site is owned by the Federal agency or the contractor. The only distinction is that RFAs at contractor sites are only valid as long as there is an active government contract, so the RFA would terminate upon contract termination. The concept of regulatory protection for contractor sites operating under RFAs is consistent with the FCC's CBRS order, which specifically referenced contractor facilities, and mirrors the comments of the Aerospace Industries Association, which proposes that contractor sites operating under an RFA have the same rights as the sites of Federal agencies. [80]

As a regulatory consideration for any of the sharing COAs described above for the 3100–3450 MHz band, DIB contractor sites operating under any license should have the same regulatory priority as sites owned and operated by the DoD or other Federal agencies.

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[80] There are significant process issues that can potentially delay the issuance of an NTIA RFA. An RFA can only be considered after a DIB contractor has obtained a DD-1494 Stage 2 certification. This application requires extensive technical data and up to 24 months to review. It can take an additional four to eight months for NTIA to issue the RFA after DoD grants Stage 2 certification. Furthermore, both the RFA and DD-1494 applications must pass through multiple DoD program offices and can be delayed due to competing priorities. Process improvements that could assist in the earlier securing of an RFA at DIB contractor facilities for the critical operations outlined in this report, especially for pre-contract and early developmental efforts, should be considered in another context.

TABLE 7.10: COA KEY TAKE AWAY SUMMARY TABLE				
	COA 1 **Active 5G RAN**	**COA 2** **DSMS**	**COA 1 + COA 2**	**COA 3** **Radar Third Generation Partnership Project (3GPP) Digital Interference Cancellation**
Overall	The advanced interference mitigation features investigated through the Active 5G Radio Access Network (RAN) Course of Action (COA) will improve the efficiency and effectiveness of the spectrum use but alone are not sufficient to make spectrum sharing feasible.	A dynamic spectrum management system (DSMS) operated within DoD that evolves the implementation of Citizens Broadband Radio Service (CBRS) in the 3550-3700 MHz band, presents a feasible spectrum sharing framework between the Federal USG systems and commercial systems in the band (with conditions). While the creation of a coordination framework based on a DSMS would make sharing feasible, commercial availability of the spectrum will continue to be impacted by critical	A dynamic spectrum management system (DSMS) that evolves the implementation of Citizens Broadband Radio Service (CBRS) in the 3550-3700 MHz band, presents a feasible spectrum sharing framework between the Federal USG systems and commercial systems in the band (with conditions). Combining the DSMS with the advanced interference mitigation features investigated through the Active 5G	At this time, RADAR 3GPP Digital Interference Cancellation is not a feasible solution for spectrum sharing.

TABLE 7.10: COA KEY TAKE AWAY SUMMARY TABLE				
	COA 1 Active 5G RAN	**COA 2 DSMS**	**COA 1 + COA 2**	**COA 3 Radar Third Generation Partnership Project (3GPP) Digital Interference Cancellation**
		airborne systems in the band that will trigger additional spectrum access limitations.	Radio Access Network (RAN) Course of Action (COA) will improve efficiency and effectiveness of the spectrum use. While the creation of a coordination framework based on a combined DSMS and Active 5G RAN interference mitigations would make sharing feasible, commercial availability of the spectrum will continue to be impacted by critical airborne systems in the band that will trigger	

TABLE 7.10: COA KEY TAKE AWAY SUMMARY TABLE				
	COA 1 **Active 5G RAN**	**COA 2** **DSMS**	**COA 1 + COA 2**	**COA 3** **Radar Third Generation Partnership Project (3GPP) Digital Interference Cancellation**
			additional spectrum access limitations.	
Technical	PRB blanking, beam muting and null steering techniques greatly improve spectrum sharing between USG and 5G commercial systems. This allows a greater spectrum sharing benefit, as compared to the baseline analysis with no Active 5G RAN interference mitigation	A DSMS capability that uses current information about 5G deployment and USG operations to optimize real-time decisions about the number of 5G sectors that must be turned off makes spectrum sharing feasible (with conditions).	A DSMS capability that uses current information about 5G deployment and USG operations to optimize real-time decisions about the number of 5G sectors that must employ interference mitigation techniques or be turned off makes	Impact on the spectrum sharing benefit of Radar 3GPP Interference Cancellation was not conducted against the baseline technical results due to low technical maturity of technology and low likelihood of a reasonable implementation path.

[redacted]

TABLE 7.10: COA KEY TAKE AWAY SUMMARY TABLE				
	COA 1 **Active 5G RAN**	**COA 2** **DSMS**	**COA 1 + COA 2**	**COA 3** **Radar Third Generation Partnership Project (3GPP) Digital Interference Cancellation**
	techniques implemented. In most cases, 5G sectors near USG systems will also need to be turned off completely to protect USG operations.		spectrum sharing feasible (with conditions) as well as improve the efficiency and effectiveness of the spectrum use when compared to a DSMS alone.	
Operational	Spectrum sharing is contingent on establishing interagency coordination mechanisms, making adjustment to training, revising readiness assessment and OPSEC.	Spectrum sharing is contingent on establishing coordination mechanisms, making adjustment to training, revising readiness assessment and OPSEC. The DSMS COA may increase operational requirements to support spectrum sharing if a notification architecture is implemented.	See COA 1 and COA 2	Requires robust integration requirements and significant operational impact due to downtime of systems to integrate interference cancellation technology.

[redacted]

TABLE 7.10: COA KEY TAKE AWAY SUMMARY TABLE				
	COA 1 **Active 5G RAN**	**COA 2** **DSMS**	**COA 1 + COA 2**	**COA 3** **Radar Third Generation Partnership Project (3GPP) Digital Interference Cancellation**
Programmatic	Requires coordination at an interagency level to accomplish timely policy and operational coordination measures.	Requires robust DoD policy and operations management organizations and supporting infrastructure. May also require a new program start to establish infrastructure to support a notification-architecture.	See COA 1 and COA 2	Integrating new capabilities on every system will require a full DoD Doctrine, Organization, Training, Materiel, Leadership, Personnel, Facilities and Policy (DOTMLPF-P) review.

Table 7.10: COA Key Take Away Summary Table

CHAPTER 8: SUMMARY AND NEXT STEPS

Overall Conclusion: Sharing of the 3100-3450 MHz band between Federal USG and commercial systems is not feasible unless certain regulatory, technological, and resourcing conditions are proven and implemented as part of a coordination framework. A coordination framework must facilitate spectrum sharing in the time, frequency, and geography domains and be fully proven through rigorous, in-depth, real-world full scope operational testing with Joint Force assets. Pursuing a dynamic spectrum management system (DSMS) operated by and within the DoD that evolves the implementation of Citizens Broadband Radio Service (CBRS) in the 3550-3700 MHz band, presents a feasible spectrum sharing framework between the Federal USG systems and commercial systems in the covered band. Combining the DSMS with the advanced interference mitigation features investigated through the Active 5G Radio Access Network (RAN) Course of Action (COA) will improve efficiency and effectiveness of the spectrum use if fully proven through rigorous, in-depth, real-world full scope operational testing with Joint Force assets and implemented in advance of any auction. These findings reflect rigorous, scientific, and evidenced-based analysis, informed and validated by industry and government, including NTIA.[81] Even with stringent adherence to a coordination framework and associated conditions, spectrum sharing between Federal and non-Federal users in the 3100-3450 MHz band will remain challenging.

While the creation of a coordination framework could make sharing feasible in the 3100-3450 MHz band assuming the conditions in Section 8.4 are met, commercial availability of the spectrum in the covered band will continue to be impacted by mission-critical airborne systems that will trigger additional spectrum access limitations. (*See classified annex*).[82] We note that NTIA is exploring development of an Incumbent Informing Capability (IIC) that the President advanced in the 2024 budget request to Congress.

The unique challenges associated with sharing spectrum used by airborne DoD systems are long-standing and well-understood.[83] In the service rules for the 3450-3550 MHz spectrum band,

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[81] President Joseph R. Biden, Jr., *Memorandum for the Heads of Executive Departments and Agencies, Subject: Memorandum on Restoring Trust in Government Through Scientific Integrity and Evidence-Based Policymaking,* Washington, DC, January 27, 2021, https://www.whitehouse.gov/briefing-room/presidential-actions/2021/01/27/memorandum-on-restoring-trust-in-government-through-scientific-integrity-and-evidence-based-policymaking/

[82] DOD, Federal agencies and NTIA will jointly assess in the future the potential applicability of uniform standardized platforms available to spectrum sharing, allowing more efficient use of the spectrum and expanding access to spectrum for both Federal and non-Federal users.

[83] *See* U.S. Department of Commerce, National Telecommunications and Information Administration, *Technical Feasibility of Sharing Federal Spectrum with Future Commercial Operations in the 3450-3550 MHz Band*, Technical Report 20-546 (January 2020), https://its.ntia.gov/umbraco/surface/download/publication?reportNumber=TR-20-546.pdf. “Due

[redacted]

FCC also recognized the continued operation of military capabilities below 3450 MHz (i.e., "the DoD will continue radar operations below 3.45 GHz as the DoD migrates some radar operation out of the 3.45-3.55 GHz band.")[84]

8.1 Overview

The Emerging Mid-Band Radar Spectrum Sharing (EMBRSS) Feasibility Assessment on the 3100-3450 MHz band was completed to conduct sharing and planning activities regarding this important mid-band spectrum range, in accordance with the Infrastructure Investment and Jobs Act (IIJA).[85] In a first-of-its kind collaboration, DoD leveraged the technical expertise of government (including the Federal Communications Commission (FCC), NTIA, and other Federal agencies), industry, and academia in support of these efforts.

The Department is submitting these findings to the Secretary of Commerce. Section 90008(b)(2)(B) of the IIJA states the Secretary of Commerce may identify frequencies within the band for reallocation "only if the Secretary of Defense has determined that sharing those frequencies with non-Federal users would not impact the primary mission of military spectrum users in the covered band."[86] In accordance with the statute, the Secretary of Defense will consider making such a determination after reviewing the proposed identification decision by the Secretary of Commerce.

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to the unique challenges with sharing the spectrum used by the nationwide airborne systems, it would be useful to study the potential to relocate the systems to another band altogether."

[84] *See* Federal Communications Commission, *In the Matter of Facilitating Shared Use in the 3100-3450 MHz Band: Report and Order and Further Notice of Proposed Rulemaking*, WT Docket No. 19-348, 35 FCC Rcd 11078 (13) (September 2, 2020), https://www.fcc.gov/document/fcc-seeks-facilitate-5g-345-355-ghz-band-0.
"In addition, the DoD's use below 3.45 GHz is expected to include ground-based and airborne operations, which may necessitate additional protection considerations."

[85] Infrastructure Investment and Jobs Act, Pub. L. No. 117-58, 135 Stat. 429 (November 15, 2021), § 90008(b), https://www.congress.gov/117/plaws/publ58/PLAW-117publ58.pdf.

[86] *Id.* at § 90008(b)(2)(3).

[redacted]

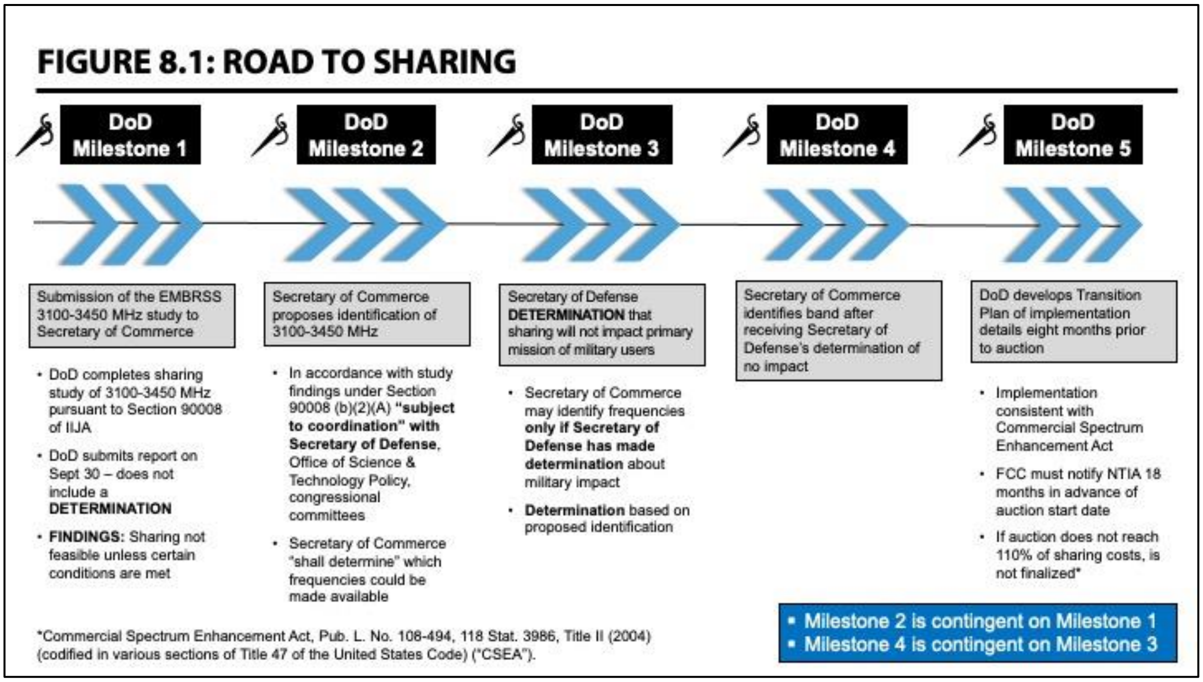

Figure 8.1: Road to Sharing

DoD relies heavily on the 3100-3450 MHz band as the physics and propagation characteristics of the covered band enable capabilities that are essential to the Department's operations and execution of the National Defense and Military Strategies. With the pacing challenge of the People's Republic of China, the acute threat posed by Russia, and threats to the U.S. Homeland, the Department conducts operations along the east and west coast of the continental United States to test and evaluate new systems, experiment with new tactics and techniques and procedures and prepare and certify forces for deployment in support of Combatant Commander missions and requirements. Every Military Department and other Federal government users, including the Department of Homeland Security, has capabilities that rely on this spectrum due to the characteristics of this band.

[redacted] Key considerations for any sharing framework must have explicit considerations concerning naval shipboard capabilities, specifically the impacts to dry dock operations. These key considerations must include: hazardous material, hardware modifications, maintenance schedules, manpower resources, supply chain limitations for producing replacement capabilities, and ship availability.

At the same time, the Department also recognizes the importance of fostering improved spectrum access for all stakeholders to promote U.S. economic competitiveness. DoD policy is to consider sharing in ways that can be accomplished without degradation to the Department's mission.

This feasibility assessment provides findings on the potential for shared spectrum access in this band.

8.2 Approach

The EMBRSS 3100-3450 MHz feasibility assessment is the most complex evaluation of the feasibility of sharing a Federal spectrum band with non-Federal users that DoD has undertaken to date. DoD operates over 120 different ground-based, shipborne, and airborne radars in the band.[87] The systems studied in the covered band represent hundreds of billions of dollars of investment and reflect acquisition life cycle timelines that span decades. The unique characteristics of the 3100-3450 MHz band support DoD's missions. By necessity, any spectrum sharing framework designed for this band will be complex to maintain the ability to execute many USG missions that are critical to the safety of our Nation and preparedness of our military to deter and, if necessary, defeat adversary aggression. Furthermore, certain military missions, such as nationwide airborne systems, present unique challenges due to their large area of operations.

The Principles Agreement signed by DoD and the Department of Commerce on December 15, 2022, jointly committed the Department and NTIA to co-lead this effort.[88] As part of ongoing collaboration and to implement the terms of the Principles Agreement, NTIA, DoD, and industry have co-chaired the NSC PATHSS TG and held technical information exchanges on key aspects of the feasibility assessment parameters and execution. As part of this ongoing engagement, NTIA has validated the technical findings of this report. FCC was also a participant in the PATHSS Task Group.[89]

In undertaking this feasibility assessment, DoD commenced both internal USG and external collaboration processes. The EMBRSS Ad Hoc Working Group supported the internal USG needs of the feasibility assessment. The membership includes representatives from the

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[87] To make the 3450-3550 MHz spectrum band available for the AMBIT auction, DoD accepted risk and many systems compressed below 3450 MHz, creating a more congested spectrum operating environment for DoD radars operating in 3100-3450 MHz.

[88] *See* Principles Agreement in **Appendix I**.

[89] *See* Federal Communications Commission, *WTB Exempts Certain Communications From Ex Parte Permit-But-Disclose Requirements: Public Notice*, WT Docket 19-348, 37 FCC Rcd 5287 (6) (April 25, 2022), https://www.fcc.gov/document/31-345-ghz-pathss-ex-parte-exemption. "Specifically, any oral or written ex parte presentations made to any Commission staff in connection with such staff's participation in the National Spectrum Consortium's Partnering on Advancing Trusted and Holistic Spectrum Solutions (PATHSS) Task Group is exempt from the permit-but-disclose requirements contained in the Commission's rules, subject to the procedure discussed below for disclosing and affording the public an opportunity to comment on any information upon which the Commission may seek to rely in the pending proceedings."

stakeholder Services, other Federal users and system program management offices (PMO), which provided support to the EMBRSS technical team, as part of their efforts to analyze the COAs for sharing in the 3100-3450 MHz band and to assess the feasibility of the COAs. Through the EMBRSS Ad Hoc Working Group, DoD was able to compile input about system operations and technical parameters that was used throughout the feasibility assessment.

In partnership with the NSC, DoD collaborated with government, industry, and academia through the PATHSS TG, which provided technical input and subject matter expertise throughout the effort. The PATHSS TG proposed COAs for analysis in the DoD feasibility assessment, which include ideas for spectrum sharing in the 3100-3450 MHz band and serve as the basis for the analysis presented in this report. PATHSS TG members provided important feedback on the analysis approach and findings as the analysis was conducted. Importantly, several stakeholders have described the effectiveness of this approach as one that should be replicated to provide an inclusive, transparent model for studying shared spectrum access.[90] For example, in comments to NTIA on the National Spectrum Strategy Charter Communications stated that it supports the "PATHSS process as a model going forward to allow the government and all of industry to work together collaboratively to find solutions to get the most out of every MHz of spectrum."[91] Similarly, in comments to NTIA on the NSS, Lockheed Martin described the PATHSS TG process as demonstrating the "benefits, both to DoD and to external stakeholders, derived from convening a venue for the co-existence both of mission requirements and typical operational architectures."[92] Additionally, during the PATHSS TG meetings, stakeholders strongly encouraged the continuation of a PATHSS TG process for implementation.

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[90] *See* Comcast Corporation, *comments to Development of a National Spectrum Strategy*, NTIA, NTIA-2023-0003-0001, 20 (April 17, 2023), https://www.ntia.gov/sites/default/files/publications/comcast.pdf.
"The DoD and National Spectrum Consortium's Partnering to Advance Trusted and Holistic Spectrum Solutions (PATHSS) Task Group has continued to evaluate this band and created a forum for industry stakeholders and the DoD to exchange sensitive and classified information on current and projected military and commercial requirements in this band. NTIA can look to this as a model for ensuring that all stakeholders can participate in the spectrum planning process." *See also* Federated Wireless, *comments to Development of a National Spectrum Strategy; Docket Number: 230308-0068*, NTIA, Docket No. 230308-006810 (April 17, 2023), https://www.ntia.gov/sites/default/files/publications/federated_wireless_0.pdf.
Noting PATHSS "could be an interesting model for NTIA to consider as it looks to ensure that all stakeholders have the ability to participate in as well as visibility into long-term spectrum planning."

[91] *See* Charter Communications, Inc., *comments to Development of a National Spectrum Strategy*, NTIA, Docket No. 230308-0068 (April 17, 2023), https://www.ntia.gov/sites/default/files/publications/charter_communications.pdf.

[92] *See* Lockheed Martin Corporation, *comments to Development of a National Spectrum Strategy*, NTIA, Docket No. 230308-0068 (April 17, 2023), https://www.ntia.gov/sites/default/files/publications/lockheed_martin.pdf.

The PATHSS TG approved 3 COAs for analysis:

- Active 5G RAN: Enables frequency sharing by having 5G network operators sense the electromagnetic spectrum and implement interference mitigation features in the local 5G RAN towers in response to the presence of incumbent system operation.

- DSMS: Enables frequency sharing through a centralized coordination system, similar to a Spectrum Access System (SAS) as used in the Citizens Broadband Radio Service (CBRS) or Automated Frequency Coordination (AFC) systems in 6 GHz band.

- RADAR 3GPP Digital Interference Cancellation: Enables frequency sharing through the use of a programmable 3GPP signal digital canceller integrated into the DoD RADAR receiver. This has the potential to decrease DoD radar sensitivity to interference from 5G to enable greater spectrum sharing, while relieving the need to share more sensitive specifications with commercial industry.

The feasibility assessment examined the technical, operational, and programmatic implications of these COAs. The technical feasibility assessment began with the development of a mature 5G deployment scenario in the band and then determined what modifications to that deployment scenario would be required to ensure 5G systems would not impact or degrade DoD missions. Three different assumptions about 5G operations in the band were considered: (1) High Power; (2) Mid Power; and (3) Low Power. The technical results include maps and tables that show DoD systems along with 5G systems and the geographic separation distance to protect USG operations when USG systems are in use.

The analysis of 16 priority systems represents the diverse array of capabilities from the Federal agencies, MILDEPs, and Services, including ground-based, shipborne, and airborne radars. These systems provided representative examples of all radar use cases and platform types that would need to be taken into consideration for a coordination framework and sharing/coexistence across all Federal systems. [redacted]

The feasibility assessment describes details of the operational impacts to DoD based on the introduction of commercial users to this band in a shared spectrum environment as described by each COA, and protections and risk mitigation measures that will need to be in place. The programmatic assessment notes the relative cost implications and schedules for implementation of each COA. Additionally, a regulatory assessment provides an overview of requirements to ensure protection of USG systems in the band. [redacted]

[redacted]

Proposed implementation details for sharing are not addressed in the findings of this report.[93] Further, the feasibility assessment only assessed interference from commercial 5G operations to USG radar systems using measured and modeled data. PATHSS did not receive any contributions or analysis from industry members on the impact from USG to commercial 5G networks outside of information that already has been shared with national policymakers.[94] The novel operational and technology issues that a spectrum-sharing regime requires for this frequency band will require good faith efforts by all stakeholders to resolve, especially considering the ongoing need for access to the 3100-3450 MHz band to execute military operations, particularly mission-critical airborne capabilities. Seaborne capabilities also have specific considerations for updating embedded capabilities, including hardware modifications, maintenance schedules, manpower resources, supply chain limitations for producing replacement capabilities, and drydock impacts.

8.3 Assessment

Sharing of the 3100-3450 MHz band between Federal USG and commercial systems is not feasible unless certain conditions are met first to facilitate spectrum sharing/coexistence in the time, frequency, and geographic domains. DoD concluded from the analysis that without a reliable mechanism for reducing or eliminating 5G emissions, USG systems will experience interference when operating in the same frequency band as 5G systems, putting missions at risk. Further, fixed geographic separation zones and frequency separation are not sufficient to enable spectrum sharing in a manner that optimizes available spectrum for shared federal and non-federal use. A framework (examples described in the spectrum sharing COAs) that facilitates spectrum sharing in the time domain to mitigate interference when and where USG systems operate must be implemented.

The framework will maximize availability of spectrum for commercial operations when USG systems are not active in the band. The spectrum sharing framework should include a technical assessment that enough spectrum will be accessible by non-Federal users to make productive use of the band. Future work is needed to estimate the availability of spectrum for non-federal users in time, frequency, and geography.

Pursuing a dynamic spectrum management system (DSMS) operated by and within the DoD that evolves the implementation of Citizens Broadband Radio Service (CBRS) in the 3550-3700 MHz band, presents a feasible spectrum sharing framework between the Federal USG systems and commercial systems in the covered band, enabling these frequencies to be auctioned. DoD alone possess the most accurate knowledge of mission critical systems, missions, and operations. Therefore, sharing is feasible if, and only if, the mission-critical systems operational in the band

[93] *See* Commercial Spectrum Enhancement Act, Pub. L. No. 108-494, 118 Stat. 3986, Title II (2004) (codified in various sections of Title 47 of the United States Code) (“CSEA”).

[94] *See* Ex Parte filed at the FCC by T-Mobile, WT Docket No. 19-348, Facilitating Shared Use in the 3100-3450 MHz Band, May 24, 2023.

[redacted]

have the capability to instantaneously detect, and immediately mitigate interference and prevent degradation to the Department's mission. This mandates the need for the DSMS to be operated by and within the DoD. Combining the DSMS with the advanced interference mitigation features investigated through the Active 5G RAN COA will improve efficiency and effectiveness of the spectrum use. The expectation is that any final sharing framework will be flexible and implement various interference mitigation techniques based on the mutual needs of the users.

Airborne Systems

The analysis concludes that USG airborne systems are particularly challenging for spectrum-sharing frameworks. Airborne systems operate at high altitudes creating line-of-sight to a large number of 5G base stations over vast geographic areas. High altitude systems also have less shielding from terrain and clutter. Airborne systems are mobile and move at high speed, as such, the large geographic area where interference mitigation required changes rapidly. Further, airborne systems do not always follow a pre-coordinated flight plan, and some flight plans are classified, so the spectrum sharing framework cannot rely on advanced coordination. As a result, the area of the country that would be forced to cease operation could be major and frequent. For these reasons, a spectrum sharing framework that protects airborne assets from interference and does not compromise the operational security must account for the extent to which commercial availability of the spectrum will continue to be limited by the ongoing necessity of mission-critical airborne systems in the band. Transitioning airborne systems to other frequencies was not addressed in this feasibility assessment. Of note, however, transition timelines and cost for [redacted] are significant with costs expected to span over 20 years or more.

Ground-Based and Shipborne Systems

Spectrum sharing in the 3100-3450 MHz band is possible for shipborne and ground-based systems in the 3100-3450 MHz band with the development and implementation of a robust coordination framework to facilitate spectrum sharing in the time domain, as well as regulatory assurances to protect USG systems from harmful interference that could impact primary USG mission operations.

The technical feasibility assessment shows that geographic separation distances and 5G network requirements to protect USG systems vary greatly depending on the system, mission, and location. The combination of COAs 1 and 2 provide knowledge of the spectrum environment through sensing or notification by incumbents, provide the most spectrum availability. Each USG system has unique operational requirements, and each commercial wireless market area has its own unique requirements. There is not a one size fits all solution to spectrum sharing. The report's findings support the feasibility of spectrum sharing framework that relies on a DSMS that evolves the implementation of CBRS in the 3550-3700 MHz band and that provides a more effective and efficient sharing framework if combined with the advanced interference mitigation features investigated through the Active 5G RAN COA. The expectation is that any final sharing framework will be flexible and implement different interference mitigation techniques based on the mutual needs for protection and service offerings.

The technical results presented in this report show the geographic separation distance of spectrum sharing using the assumptions, inputs, and modeling approaches employed in this feasibility assessment. Technical results could differ greatly depending on the real-world results and modeling inputs. Industry developed standards were used wherever possible in this assessment to ensure consistency with accepted methods. To support the development of a spectrum sharing framework in this band, DoD will work with stakeholders to further refine the analysis for implementation with inputs based on realistic deployments. Different assumptions regarding 5G deployments or DoD operations could change the spectrum sharing operational parameters. However, the finding that spectrum sharing in the 3100-3450 MHz band can only be accomplished with a robust coordination framework and the conditions detailed in Section 8.4 will remain fixed, even if the aforementioned assumptions change.

[redacted]

- [redacted]
- [redacted]
- [redacted]
- [redacted]
- [redacted]

The technical results presented in this feasibility assessment may be used as a factor for establishing rules for licensed commercial wireless services introduced in the covered band. DoD will continue to refine modeling techniques to reduce uncertainty.

A regulatory framework must be implemented to address the coordination requirements, enforcement protocols, and security needed to enable sharing in the 3100-3450 MHz band without impacting military operations.

DoD recognizes the benefit of improving resilience of radar systems to interference and increasing EMS survivability. Each system has unique integration requirements, it is premature to make a determination if retrofitting existing platforms with interference cancellation techniques.

8.4 Conditions for Spectrum Sharing

Sharing is not feasible unless the following conditions for shared federal/non-federal use in the 3100-3450 MHz band are met:

- **DoD retains regulatory primacy:** Section 90008(b)(2)(B) of the IIJA states the Secretary of Commerce may identify frequencies that could be made available on a shared basis "only if the Secretary of Defense has determined that sharing those frequencies with non-Federal users would not impact the primary mission of military spectrum users in the covered band." As a condition of spectrum sharing, Federal radiolocation operation shall retain a primary allocation status in this frequency range with the potential development of a footnote, if needed, to ensure that "all practical steps shall be taken" to protect Federal radiolocation operations from harmful interference; this is in line with other US footnote protections to the Table of Allocations under Section 47 C.F.R. § 2.106.

- **National emergency preemption policy is maintained:** The national emergency pre-emption policy must be maintained, with an understanding that any impact to the availability of commercial wireless services is part of a broader ecosystem of civilian infrastructure that also potentially affects DoD actions (i.e., transportation systems, power grids, etc.).

- **Expand/improve existing CBRS sharing framework policy and technology:** CBRS is a field-proven model in which DoD retains regulatory primacy, when sharing spectrum between Federal and non-Federal users. Therefore, the CBRS sharing framework can be evolved and scaled to meet DoD mission requirements. The expectation is that any final sharing framework will be flexible and employs different interference mitigation techniques based on the mutual needs for protection and service offerings.

- **USG is not liable for damages to commercial systems:** USG does not assume liability for damages to commercial system hardware resulting from radar operations. Regulatory protections for this band will address the unique security concerns related to information transmitted to, or required from, 5G licensed commercial wireless users as part of the employment of a spectrum sharing coordination framework, including both sensing and notification provisions.

- **Address information, operational, and cyber security concerns:** As a result of the operational analysis conducted by DoD to address the operational security requirements of the Services and minimize the exposure to cyber threats, the DSMS must be operated by and within the DoD.[95] A regulatory framework must be implemented to address the coordination requirements, enforcement protocols, informational needs, and cyber and operational security to enable sharing in the 3100-3450 MHz spectrum without impacting military operations.

- **DIB retains band access for testing and experimentation:** Radar manufacturing and integration facilities require access to the 3100-3450 MHz spectrum band to perform experimentation and testing for radionavigation and other systems contracted by DoD and other Federal agencies. It is imperative that these facilities retain access to this band for testing and experimentation purposes so that DoD and other Federal agencies' contracting requirements can be fulfilled.

- **Current and future Federal systems are accommodated equally:** The technical and regulatory framework will accommodate current and future Federal operations with an acknowledgement that commercial availability of the spectrum will continue to be limited by the ongoing necessity of mission-critical airborne systems in the band.

- **Establish interference safeguards:** Federal users are not required to assume the responsibility of mitigating interference from USG operations to 5G users. Non-Federal users must not cause harmful interference to Federal incumbent users and Non-Federal users must accept interference from Federal incumbent users.

- **Resource requirements addressed:** Cost and resource issues must be addressed, including for sustainment of a coordinated framework. These issues should be taken into consideration for cost reimbursements from the SRF and any associated funding gaps, including long-term sustainment of sharing coordination frameworks.

8.5 Way Forward

A complicating factor in this feasibility assessment has been the increased packing of federal systems relocated from other bands, including those as a result of repurposing from previous auctions. This concern is amplified when additional repurposing actions are contemplated before the transition activities from previous repurposing efforts are complete. As spectrum becomes more and more congested, and the heterogeneity of S-D systems occupying the same temporal, geospatial, and spectral domains increases, the need for study, research, development, prototyping, testing, and validation of coexistence and sharing solutions *prior to* repurposing becomes even more imperative.

Further, sharing between Federal radar capabilities and non-Federal mobile wireless systems presents unique challenges, especially for airborne operations. Seaborne capabilities as part of a sharing framework also have specific considerations for updating embedded capabilities, including hardware modifications, maintenance schedules, manpower resources, supply chain

[redacted]

limitations for producing replacement capabilities and drydock impacts. Radars must be able to distinguish very weak reflected energy from ambient noise. The introduction of even low power licensed commercial communications systems in the same band mask weak receive signals.

Spectrum sharing analyses are conducted by modeling the coexistence of systems. Having models that are as accurate as possible is mutually beneficial to all parties involved in spectrum sharing, and there is a desire to validate and improve modeling capabilities and standardize best practices. Previous modeling for the systems involved have focused on avoiding simultaneous use of the evaluated bands. The more complex nature of radar and radio coexistence stressed the models leading, in some cases, to more granular assessments than would be optimal should radar-radio coexistence become a normal operational reality. Testing and measurements are fundamental to model validation and will help ensure confidence in results. Some specific areas for testing and measurement that will help augment and refine the findings of this feasibility assessment could include:

- Lab and field testing/measurements for USG systems to refine the receiver characterization used in models. Possible refinements include but are not limited to:
    - Receiver selectivity curves
    - Interference Protection Criteria (IPC)
        - Including receiver interference resilience features
    - Operating mode dependencies
    - Electromagnetic protection features
    - Antenna patterns to include use of angular and time discrimination mitigations
    - RADAR receive element recovery when operated in concert with 5G active mitigation techniques close to pulse receive periods

- Propagation measurements targeted to the 3100-3450 MHz band. Possible refinements include but are not limited to:
    - Clutter loss due to buildings and foliage
    - Building entry/exit loss
    - Losses due to terrain
    - Losses dues to atmospheric effects
        - Direct and indirect path ducting, glint and other phenomena
        - Troposcatter effects between RADAR and Radio mixed transmit and receive elements.

- Lab and field testing/measurements for commercial wireless systems to refine the emission models. Possible refinements include but are not limited to:
    - Transmitter emission curves
        - Includes out-of-band unwanted and spurious emissions
        - AAS mitigation technique impacts (beam steering, nulling and others)
    - Scheduler features
        - Includes transmitter power control features
        - Includes PRB Blanking
    - Antenna patterns

    - Includes out-of-band frequency response
    - Includes beam muting and nulling features

Future work could also include:

- Improvements to commercial wireless deployment models based on real-world data
    - Includes improvements to model low-height, downward facing, low-power only microcell deployments (like those envisioned for DAS and Fixed Wireless to the home or office)
    - Assessment of alternate deployment models that are possible though not currently in use
    - Leveraging advanced technologies and spectrum management techniques that improve the compatibility of systems to better enable co-existence to address the growing demand for access to an increasingly congested and constrained EMS
    - Assessment of the potential for new-start RADAR systems designed to co-exist in both cooperative and non-cooperative commercial wireless networks

Additional data may be needed to notify the DSMS of USG system use that is not currently collected or maintained in a consistent manner. Fundamentally, DSMS requires accurate information regarding USG systems, including consistent data collection, refinement, and maintenance. As a first step to assess the gaps in what data is currently collected and what would be needed to notify the DSMS, DoD should perform a gap analysis to determine what data is available, at what resolution, and how the data is captured, and determine what information would be necessary to notify a DSMS of planned or impromptu spectrum requirements. To further refine the gap analysis, DoD could conduct site-specific analysis to characterize time of use data of the systems with either large uncertainties of time use and/or large geographic coordination areas. While USG system frequency assignment data can be used to estimate the time of use data of systems at specific sites, it is not granular enough to support and implement a spectrum sharing solution required for the 3100 – 3450 MHz band. While the desire is to remain at the lowest level of classification necessary, where these increased data requirements place security classification requirements on industry, it is the most effective spectrum sharing that will be emphasized, not minimizing classification.

8.6 Findings

The DoD feasibility assessment is complete in accordance with Section 90008 of the IIJA, and the Secretary of Defense is reporting these findings to the Secretary of Commerce in accordance with Section 90008 (b)(1)(C). For the above reasons, identifying the 3100-3450 MHz band for shared Federal and non-Federal use is feasible if, and only if, the conditions enumerated in **Section 8.4** are met. The report's findings indicate that a DSMS, that evolves the CBRS framework in the 3550-3700 MHz band, with advanced interference mitigation features which can address the needs of all systems, including the unique needs of airborne systems, provides a feasible path forward for spectrum sharing between the Federal and commercial systems in the 3100-3450 MHz band.

The Department of Defense looks forward to implementing the next steps required by Section 90008, starting with coordination with the Secretary of Commerce under Section 90008 (b)(2)(A). In accordance with this subsection, "the Secretary of Commerce, in coordination with the Secretary of Defense, the Director of the Office of Science and Technology Policy, and relevant congressional committees, shall—(i) determine which frequencies of electromagnetic spectrum in the covered band could be made available on a shared basis between Federal use and non-Federal commercial licensed use, subject to flexible use service rules; and (ii) submit to the President and the Commission a report that identifies the frequencies determined appropriate under clause (i)."

The completion of this report does not automatically result in sharing the 350 MHz of spectrum in this band; additional steps are required by the Secretary of Commerce, and subject to a determination by the Secretary of Defense that spectrum sharing will not impact the primary mission of military spectrum users. Additional planning activities may be required, including those related to the implementation of a coordination framework and the nine conditions in the findings above. Further, use of this spectrum is dependent on promulgation of service rules by FCC as part of future public rulemakings.

Beyond the scope of the IIJA and the EMBRSS Feasibility Assessment, DoD remains committed to spectrum sharing and coexistence for the benefit of the entire Nation and all stakeholders.

LIST OF ABBREVIATIONS AND ACRONYMS

LIST OF ABBREVIATIONS AND ACRONYMS	
Abbreviation or Acronym	**Definition**
3GPP	Third Generation Partnership Project
A&D	Aerospace and Defense
AAA	Anti-Aircraft Artillery
AAS	Advanced Antenna System
AAW	Anti-Air Warfare
AD/SR	Air Defense/Surveillance Radar
ADAMS	Advanced Dynamic Aircraft Measurement System
AFB	Air Force Base
AFC	Automatic Frequency Coordination
AI	Airborne Interceptors
AMBIT	America's Mid-Band Initiative Team
APT	Antenna Pattern Tool
ARPA	Automatic Radar Plotting Aid
ATC	Air Traffic Control
[redacted]	[redacted]
AWGN	Additive White Gaussian Noise
AWS	Advanced Wireless Services
AWS-1	Advanced Wireless Services-1
AWS-3	Advanced Wireless Services-3
BCT	Brigade Combat Team
BMD	Ballistic Missile Defense
BS	Base Station
C2	Command and Control

LIST OF ABBREVIATIONS AND ACRONYMS	
Abbreviation or Acronym	**Definition**
C2BM	C2 Battle Management
C3	Command, Control, and Communications
C3LB	C3 Leadership Board
CATC	Carrier ATC
CBRS	Citizens Broadband Radio Service
CBRN	Caribbean Basin Radar Network
CCA	Carrier Controlled Approach
CCDR	Combatant Commander
CDF	Cumulative Distribution Function
CERTAIN	City Environment for Range Testing of Autonomous Integration Navigation
CIO	DoD Chief Information Officer
CITEL	Organization of American States - Inter-American Telecommunication Commission
COA	Course of Action
CONUS	Continental United States
CPA	Cooperative Planning Area
CQI	Channel Quality Indicator
[redacted]	[redacted]
CSG	Carrier Strike Group
CSI	Channel State Information
CSMAC	Commerce Spectrum Management Advisory Committee
C-sUAS	Counter-Small UAS
C-UAS	Counter UAS
CUI	Controlled Unclassified Information

LIST OF ABBREVIATIONS AND ACRONYMS	
Abbreviation or Acronym	**Definition**
[redacted]	[redacted]
Department	Department of Defense
DF	Direction Finding
DHS	Department of Homeland Security
DIB	Defense Industrial Base
DIRLAUTH	Direct Liaison Authority
DoD	Department of Defense
DOT&E	Director, Operational Test and Evaluation
DSM	Digital Surface Model
DSMS	Dynamic Spectrum Management System
DSP	Digital Signal Processing
E3	Electromagnetic Environmental Effects
EA	Electromagnetic Attack
EASY	Environmental Analysis System
ECCM	Electronic Counter-Countermeasures
EIRP	Effective Isotropic Radiated Power
ELCID	Equipment Location-Certification Information Database
EM	Electromagnetic
eMBB	Enhanced Mobile Broadband
EMBRSS	Emerging Mid-Band Radar Spectrum Sharing
EME	Electromagnetic Environment
EMI	Electromagnetic Interference
EMP	Electromagnetic Pulse
EMS	Electromagnetic Spectrum

LIST OF ABBREVIATIONS AND ACRONYMS	
Abbreviation or Acronym	**Definition**
ES	Electromagnetic Sense
ESD	Electrostatic Discharge
EUCOM	U.S. European Command
EW	Electromagnetic Warfare
Fast Track Report	2010 NTIA "fast track" assessment of accommodating wireless broadband systems in five bands to recommend spectrum that could be made available in the short term
FCC	Federal Communications Commission
FDR	Frequency Dependent Rejection
FMS	Foreign Military Sales
FWA	Fixed Wireless Access
FY	Fiscal Year
[redacted]	[redacted]
GAA	General Authorized Access
[redacted]	[redacted]
[redacted]	[redacted]
GEO	Geosynchronous Orbit
GIS	Geographic Information System
GMF	Government Master File
GSD	Geographic Separation Distance
GWLR	Ground Weapons Locating Radar
HRR	High Range Resolution
I/N or INR	Interference to Noise Ratio
IEEE	Institute of Electrical and Electronic Engineers
IIJA	Infrastructure Investment and Jobs Act

LIST OF ABBREVIATIONS AND ACRONYMS	
Abbreviation or Acronym	**Definition**
IMC	Instrument Meteorological Condition
IMT	International Mobile Telecommunications
INDOPACOM	U.S. Indo-Pacific Command
IoT	Internet of Things
IPC	Interference Protection Criteria
ISAR	Inverse Synthetic Aperture Radar
ISD	Inter-Site Distance
ISRO	Indian Space Research Organization
ITM	Irregular Terrain Model
ITU	International Telecommunication Union
ITU-R	ITU Radiocommunication Sector
JEM	Jet Engine Modulation
JETS	Joint EW Test and Evaluation Strategy
KE	Knife Edge
kHz	Kilohertz
km	Kilometer(s)
LFE	Large-Force Exercise
LILDRST	Lincoln Laboratory Distributed Remote Sensing Testbed
LO	Low-Observable
LOS	Line-of-Sight
[redacted]	[redacted]
m	Meter(s)
MACCS	Marine Air Command and Control System
MAF	Mobility Air Force

LIST OF ABBREVIATIONS AND ACRONYMS	
Abbreviation or Acronym	**Definition**
mBB	Mobile Broadband
MDA	Missile Defense Agency
[redacted]	[redacted]
MHR	Multi-Mission Hemispheric Radar
MHz	Megahertz
MIMO	Multiple-Input Multiple-Output
MOBILE NOW	Making Opportunities for Broadband Investment and Limiting Excessive and Needless Obstacles to Wireless
mRR	Modified Randomized-Real
MRTFB	Major Range and Test Facility Base
M-SHORAD	Maneuver-Short Range Air Defense
MTS	Moving Target Simulator
MVNO	Mobile Virtual Network Operator
NASA	National Aeronautics and Space Administration
NAVSEA	Naval Sea Systems Command
NAWCAD	Naval Air Warfare Center Aircraft Division
NAWCWD	Naval Air Warfare Center Weapons Division
NCR	Network Cooperative Radar
NDS	National Defense Strategy
NEXRAD	Next Generation Weather Radar
NF	Noise Figure
NFL	New Foreign Launch
NISAR	NASA-ISRO SAR
NLCD	National Land Cover Database
NLOS	Non-LOS

LIST OF ABBREVIATIONS AND ACRONYMS	
Abbreviation or Acronym	**Definition**
NPT	Network Planning Tool
NRTF	National Radar Cross Section Test Facility
NSC	National Spectrum Consortium
NTIA	National Telecommunications and Information Administration
NTTR	Nevada Test and Training Range
OET	Office of Engineering and Technology
OMB	Office of Management and Budget
OOB	Out-of-Band
OPTEMPO	Operational Tempo
ORV	Operational Requirements Verification
OSTP	Office of Science and Technology Policy
PATHSS	Partnering to Advance Trusted and Holistic Spectrum Solutions
PATHSS-C	PATHSS-Classified
PDF	Probability Distribution Function
PDSCH	Physical Data Shared Channel
Plan and Timetable	Plan and Timetable to Make Available 500 Megahertz of Spectrum for Wireless Broadband
PMI	Precoding Matrix Indicator
PMO	Program Management Office
ppsm	Persons per Square Mile
PRACH	Physical Random Access Channel
PRB	Physical Resource Block
PSD	Power Spectral Density
PUA	Periodic Use Area
Quadriga	Quasi Deterministic Radio Channel Generator

LIST OF ABBREVIATIONS AND ACRONYMS	
Abbreviation or Acronym	**Definition**
R&D	Research and Development
RAM	Rocket, Artillery, and Mortar
RAN	Radio Access Network
RCIED	Radio Controlled Improvised Explosive Device
RCS	Radar Cross Section
RDT&E	Research, Development, Test, and Evaluation
RF	Radio Frequency
RI	Rank Indicator
ROM	Radius of Mobility
RSDE	Radar Signal Density Enhancement
RSE	Radar Signal Emulator
RWR	Radar Warning Receiver
S&T	Science and Technology
SAG	Surface Action Group
SAM	Surface-to-Air Missile
SAP	Special Access Program
SAR	Synthetic Aperture Radar
SAS	Spectrum Access Systems
SDA	Space Domain Awareness
SENSR	Spectrum Efficient National Surveillance Radar
SESEF	Shipboard Electronic Systems Evaluation Facilities
SINR	Signal-to-Interference-Plus-Noise Ratio
SKE	Station Keeping Equipment
SoS	System of Systems

LIST OF ABBREVIATIONS AND ACRONYMS	
Abbreviation or Acronym	**Definition**
SRF	Spectrum Relocation Fund
SSB	Synchronization Signal Block
SSG	Senior Steering Group
STATGAIN	Statistical Antenna Gain
T&E	Testing and Evaluation
TACS	Theater Air Control System
TDD	Time Division Duplex
TG	Task Group
TIREM	Terrain Integrated Rough Earth Model
TRMC	Tri-Service Realistic Threat Representations
TTPs	Tactics, Techniques and Procedures
UA	Unmanned Aircraft
UAS	Unmanned Aerial System
UAV	Unmanned Aerial Vehicle
UE	User Equipment
UL	Uplink
ULA	Uniform Linear Array
ULSA	Ultra-Low Sidelobe Antenna
US&P	United States and Possessions
USA	U.S. Army
USAF	U.S. Air Force
USG	U.S. Government
USGS	U.S. Government System
USMC	U.S. Marine Corps

LIST OF ABBREVIATIONS AND ACRONYMS	
Abbreviation or Acronym	**Definition**
USN	U.S. Navy
USSF	U.S. Space Force
WiMAX	Worldwide Interoperability for Microwave Access
WSMR	White Sands Missile Range
WTB	Wireless Telecommunications Bureau