EVALUATION OF THE 5350-5470 MHZ AND 5850-5925 MHZ BANDS PURSUANT TO SECTION 6406(b) OF THE MIDDLE CLASS TAX RELIEF AND JOB CREATION ACT OF 2012

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EXECUTIVE SUMMARY

Through this report, the National Telecommunications and Information Administration (NTIA) presents the results of its initial study on the potential use of up to 195 megahertz of spectrum in the 5 gigahertz (GHz) band by Unlicensed-National Information Infrastructure (U-NII) devices. Pursuant to Section 6406(b)(1) of the Middle Class Tax Relief and Job Creation Act of 2012 (Tax Relief Act),[1] NTIA, in consultation with the Department of Defense and other impacted agencies, assessed known and proposed spectrum-sharing technologies. This study also evaluated the risk to federal users if the Federal Communications Commission (FCC) allows U-NII devices to operate in the 5350-5470 MHz and 5850-5925 MHz bands.[2]

Under current FCC regulations, U-NII devices are authorized to use 555 megahertz of spectrum in the 5150-5350 MHz and the 5470-5825 MHz bands subject to specific technical and operational restrictions to enable sharing with protected radar and satellite operations. U-NII devices provide short-range, high-speed unlicensed wireless connections in the 5 GHz band for, among other applications, Wi-Fi-enabled radio local area networks, cordless telephones, and fixed outdoor broadband transceivers used by wireless internet service providers. Unlicensed wireless broadband systems have become critical complements to licensed commercial mobile networks and to fixed wireline networks. For example, smart phones, tablets, net-books and laptops typically have inexpensive embedded Wi-Fi capabilities that enable high-speed broadband connectivity in a wide array of locations.

International industry standards currently under development will enable the provision of significantly higher data throughput in the 5 GHz bands by using wider radiofrequency (RF) bandwidths, more data streams, and high-density signal modulation techniques. The wider RF bandwidth requirements may require larger blocks of contiguous frequencies and expanding the amount of spectrum authorized for U-NII device operation in the 5 GHz band will increase the contiguous spectrum that is available.

Several federal agencies currently use the two potential 5 GHz expansion bands that are the subject of this study. Federal systems in these bands include a variety of radar systems installed on airborne, ground-based, shipborne, and space-based platforms. In addition to radar operations, federal users operate a number of airborne RF communications systems at sites across the United States in these bands to conduct, for example, testing and training of unmanned

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[1] Pub. Law No. 112-96, § 6406(b)(1), 126 Stat. 231 (Feb. 22, 2012).

[2] Section 6406(b)(2) of Tax Relief Act requires the Assistant Secretary of Commerce for Communications and Information to submit to the FCC and the Committee on Energy and Commerce of the House of Representatives and the Committee on Commerce, Science, and Transportation of the Senate a report on the portion of the study with respect to the 120 megahertz in the 5350-5470 MHz band not later than eight months after the date of enactment (*i.e.*, by October 22, 2012). It further requires the Assistant Secretary to submit a report on the portion of the study with respect to the 75 megahertz in the 5850-5925 MHz band not later than 18 months after the date of enactment (*i.e.*, by August 22, 2013). NTIA, in consultation with the affected agencies, has conducted a qualitative study of both bands identified in the legislation and has combined the results into this single report.

aircraft systems (UAS) data and command links for intelligence, surveillance, reconnaissance and combat search and rescue missions. The Department of Homeland Security also operates UAS in the 5350-5470 MHz band for drug interdiction and border surveillance operations. In the 5850-5925 MHz band, additional allocated and authorized uses include non-federal fixed-satellite uplinks (Earth-to-space) and federal and non-federal mobile services. The non-federal mobile service allocation is limited to Dedicated Short Range Communications Service (DSRCS) systems operating in the Intelligent Transportation System radio service.

For this study, NTIA assumed that the federal agencies will not alter their systems or operations to accommodate U-NII devices on a shared basis in the potential 5 GHz expansion bands. NTIA also based its analysis on an assumption that the FCC's existing requirements for situation-aware spectrum-sharing technologies that apply in some of the existing 5 GHz bands would be used to enable access to additional spectrum by new U-NII devices while preserving the mission capabilities of federal users. These current requirements that are implemented in certified and deployed equipment include transmitter power control (TPC) and dynamic frequency selection (DFS) approaches. However, as directed by Congress, in addition to these technical capabilities, NTIA also examined a range of known and proposed spectrum-sharing technologies and approaches, including sensing, geo-location database methods, and other potential co-existence measures and safeguards.

Based on these known and proposed spectrum-sharing technologies and approaches, this report identifies a number of risk elements due to the likelihood of harmful interference from large numbers of U-NII devices to protected federal systems in the 5350-5470 MHz and 5850-5925 MHz bands. The report discusses suggested mitigation strategies for each risk element. For example, the report identifies potential risks for federal airborne, ground-based, and shipborne radar systems related to changes in radar signal parameters or changes to U-NII device deployment and technical parameters, which current regulations may not be equipped to adequately address. Another risk element is that existing U-NII regulations were not developed to detect airborne signals. Suggested mitigation strategies include the development of representative technical parameters and sharing scenarios where the transmitters and receivers are not co-located to perform quantitative analysis to evaluate whether current regulations would protect airborne operations. The report also addresses risks and mitigation strategies to protect spaceborne receivers.

The report concludes that further analysis will be required to determine whether and how the identified risk factors can be mitigated through, for example, the promulgation of new safeguards in addition to the FCC's existing requirements. Accordingly, NTIA, in collaboration with the federal and industry stakeholders and the FCC, will conduct quantitative analysis of potential mitigation requirements in connection with regulatory proceedings. In the next phase of its assessments, NTIA will lead detailed quantitative studies described more fully in this report, which will include additional analysis and measurements to evaluate the feasibility of existing, modified, proposed and new spectrum-sharing technologies and approaches. These studies will be supported by and involve direct interaction between federal and non-federal stakeholders, including representatives of the wireless industry and the intelligent transportation community. In addition, NTIA, the FCC, the State Department and the other affected federal agencies will continue to work cooperatively with industry representatives and international partners to fully assess various sharing scenarios in these bands and to address the international dimensions and ramifications of these issues.

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SECTION 1. INTRODUCTION

BACKGROUND

Section 6406(b)(1) of the Middle Class Tax Relief and Job Creation Act of 2012 (Tax Relief Act) requires the Assistant Secretary of Commerce for Communications and Information (Assistant Secretary), in consultation with the Department of Defense (DoD) and other impacted agencies, to conduct a study evaluating known and proposed spectrum-sharing technologies and the risk to federal users if the Federal Communications Commission (FCC) allowed Unlicensed-National Information Infrastructure (U-NII) devices to operate in the 5350-5470 MHz and 5850-5925 MHz bands.[1] Under current FCC regulations, U-NII devices are authorized to use 555 megahertz of spectrum in the 5150-5350 MHz and the 5470-5825 MHz bands subject to specific technical and operational restrictions to enable sharing with protected radar and satellite operations.[2]

U-NII devices provide short-range, high-speed unlicensed wireless connections in the 5 GHz band for, among other applications, Wi-Fi-enabled radio local area networks, cordless telephones, and fixed outdoor broadband transceivers used by wireless internet service providers.[3] Unlicensed wireless broadband systems have become critical complements to licensed commercial mobile networks and to fixed wireline networks. For example, smart phones, tablets, net-books and laptops typically have inexpensive Wi-Fi capabilities that enable high-speed broadband connectivity in a wide array of locations.[4]

OBJECTIVE

The objective of this study was to evaluate known and proposed spectrum-sharing technologies and the risks to federal systems associated with allowing U-NII devices to operate in both the 5350-5470 MHz band and the 5850-5925 MHz band. Although the Tax Relief Act contemplates separate reports on both of the two potential 5 GHz expansion bands, this study

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[1] Pub. Law No. 112-96, § 6406(b)(1), 126 Stat. 156 at 231 (Feb. 22, 2012).

[2] *See generally* 47 C.F.R. Part 15, Subpart E; Revision of Parts 2 and 15 of the Commission's Rules to permit Unlicensed National Information Infrastructure (U-NII) devices in the 5 GHz band, *Report and Order* in ET Docket No. 03-122, FCC 03-287 (2004), *available at* http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-03-287A1.pdf (U-NII Report and Order); *Memorandum and Opinion Order*, ET Docket No. 03-122, FCC 06-96 (2006), *available at* http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-06-96A1.pdf (*U-NII Reconsideration Order*).

[3] The Wi-Fi suite of protocols includes IEEE 802.11b and 802.11g in the 2.4 GHz band, and IEEE 802.11a in the 5.7 GHz band. *See* Kenneth Carter, Ahmed Lahjouji, and Neal McNeil, *Unlicensed and Unshackled: A Joint OSP-OET White Paper on Unlicensed Devices and Their Regulatory Issues,* Office of Strategic Planning and Policy Analysis Working Paper Series 39 (May 2003), *available at* http://www.fcc.gov/working-papers/unlicensed-and-unshackled-joint-osp-oet-white-paper-unlicensed-devices-and-their-regu.

[4] *See* FCC, Connecting America: The National Broadband Plan, Chapter 5 (Mar. 2010), *available at* http://www.broadband.gov/plan/5-spectrum

combines them into a single report. Authorized incumbent systems other than those operated by the Federal Government are also evaluated.[5]

APPROACH

NTIA, in consultation with the DoD and other impacted agencies, assessed known and proposed spectrum-sharing technologies and the risks to federal users associated with the potential introduction of U-NII devices in the 5350-5470 MHz and 5850-5925 MHz bands. The types of spectrum sharing technologies assessed include sensing-based approaches, geo-location/database approaches, and the use of beacons to signal the availability of frequencies to devices in a particular area.

The risks identified in this report relate to the likelihood of harmful interference to systems operated by federal users and the study assumed that the FCC's existing U-NII transmit power control (TPC) and dynamic frequency selection (DFS) regulations would be extended to the 5350-5470 MHz and 5850-5925 MHz bands.[6] Another assumption was that the federal agencies will not have to alter their systems or operations to accommodate U-NII devices. The FCC authorizes U-NII devices under Part 15 of its rules, which provide that U-NII devices must operate on a non-interference basis.[7] For each risk identified, the report discusses a suggested mitigation strategy and whether the strategy may adequately address the identified risk.

NTIA developed, in collaboration with the federal agency members of the Policy and Plans Steering Group (PPSG), a work plan for evaluating the risks to federal systems operating in the 5350-5470 MHz and 5850-5925 MHz bands. The plan outlined and requested the technical and operational information necessary to perform the evaluation. Several federal agencies also conducted preliminary electromagnetic compatibility and interference analyses to begin to quantify risks to their systems.

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[5] Non-federal radar systems are authorized by the FCC to operate in the 5350-5470 MHz band. The military agencies lease capacity on commercial satellite systems authorized by the FCC operating in the 5850-5925 MHz band. In addition, any licensee authorized to operate DSRC roadside units may share their facilities with Federal Government entities and these entities may also deploy.

[6] The specific language in the Tax Relief Act referred to "risk to Federal users". This study considered harmful interference to systems operated by federal users as well as systems that are used by non-federal users. "Harmful interference" is 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 these Regulations. "Interference" is the effect of unwanted energy due to one or a combination of emissions, radiations, or inductions upon reception in a radiocommunication system, manifested by any performance degradation, misinterpretation, or loss of information, which could be extracted in the absence of such unwanted energy. NTIA, *Manual of Regulations and Procedures for Federal Radio Frequency Management* at 6.1.1.

[7] One of the principal operating conditions for equipment authorized under Part 15 is the operator must accept whatever interference is received and must correct whatever interference is caused. 47 C.F.R. Part 15, Subpart A (§§ 15.3(m) and 15.5); *see also id*. at Subpart E.

NTIA also received initial input from wireless industry stakeholders related to the projected technical and deployment parameters for U-NII devices,[8] and reviewed domestic and international technical studies used in the development of the existing U-NII regulations in performing this evaluation.[9] NTIA is using the results of this evaluation to identify areas where direct interaction with wireless and transportation industry representatives is necessary and where more detailed quantitative analysis would be fruitful. These analyses and measurements could require iterative responses and constructive discussions by industry and government stakeholders.

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8 *See* Letter from Mary L. Brown, Director, Government Affairs, Cisco Systems, Inc. to Karl Nebbia, Associate Administrator, Office of Spectrum Management, NTIA (Sept. 26, 2012) (*Industry Input*).

9 There are several International Telecommunication Union-Radiocommunication (ITU-R) sector recommendations related to DFS referenced throughout this report.

SECTION 2. SPECTRUM-SHARING TECHNOLOGIES

INTRODUCTION

The Tax Relief Act requires NTIA, in consultation with DoD and other impacted agencies, to evaluate known and proposed spectrum-sharing technologies. This section provides an overview of spectrum-sharing approaches and technologies that have been recently authorized, identified, and addressed by the FCC as well as expert advisors to the President, NTIA, and the FCC. The President's Council of Advisors on Science and Technology (PCAST) prepared a report that examined how advances in situation-aware spectrum-sharing technologies could facilitate commercial use while preserving the mission capabilities of federal users.[12] The PCAST report notes that existing approaches to spectrum sharing can be augmented by a variety of means, including dynamic redirecting of devices to available frequencies and better prevention of harmful interference among signals in close proximity to one another. The Commerce Spectrum Management Advisory Committee (CSMAC) made recommendations on using dynamic spectrum access and geo-location/database approaches to offer new opportunities to increase spectrum sharing.[13] Although spectrum-sharing technologies and methods have existed for decades, primary modern spectrum-sharing technologies use sensing-based approaches and geo-location/database approaches. Another new approach uses beacons or pilot channels to signal the availability of frequencies to devices in a particular area.

DFS, which is required by the FCC in certain bands authorized for U-NII devices, monitors the spectrum and selects for operation a frequency that is not already in use. For instance, prior to the start of any transmission, a U-NII device equipped with DFS capability must continually monitor the radio frequency environment for the presence of a radar signal. If a U-NII device determines that a radar signal is present, it must either select another channel or enter a "sleep mode" if no channels are available.[14]

The FCC also adopted rules for Television Band Devices (TVBDs) that allow unlicensed devices to share unused television channels so long as the devices employ a geo-location database or sensing capability to determine if a channel is available.[15] The FCC initially relied

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[12] President's Council of Advisors on Science and Technology (PCAST), Realizing the Full Potential of Government-Held Spectrum to Spur Economic Growth at 30 (July 20, 2012) (*PCAST Report*), *available at* http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast_spectrum_report_final_july_20_2012.pdf.

[13] NTIA, Commerce Spectrum Management Advisory Committee, Final Report of the Interference and Dynamic Spectrum Access Subcommittee (Nov. 8, 2010) (*CSMAC Subcommittee Final Report*), *available at* http://www.ntia.doc.gov/files/ntia/publications/interference-dynamic_spectrum_access_subcommittee.pdf.

[14] *See* U-NII Reconsideration Order at ¶ 3; U-NII Report and Order at 4.

[15] *See* Unlicensed Operation in the TV Broadcast Bands, *Second Report and Order and Memorandum Opinion and Order*, ET Docket No. 04-186, FCC 08-260 (2008), *available at* http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-08-260A1.pdf; *Second Memorandum Opinion and Order*, ET Docket No. 04-186, FCC 10-174 (2010), *available at* http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-10-174A1.pdf (TV White Space Second Reconsideration Order); *Third Memorandum Opinion and Order*, ET

on spectrum sensing and geo-location combined with access to a database of existing spectrum use to determine if a channel is available. On reconsideration, the FCC eliminated the combined sensing/database requirement, and retained the geo-location database as the primary spectrum access approach, but authorized a sensing-only method based on certain criteria and conditions.[16] The FCC has authorized a number of private database administrators and has begun the certification of TVBDs.[17]

The FCC's rules governing operations in the 3650-3700 MHz band for licensed wireless broadband facilitate spectrum sharing through a flexible nationwide license, a database registration requirement for specific locations, and a requirement that operations employ contention-based protocols.[18] The FCC relied on the wireless industry to develop standards for implementing this requirement, and equipment meeting this requirement is increasingly finding its way into the market. For example, the Institute for Electrical and Electronics Engineers (IEEE) standard 802.11y-2008 is an amendment to the IEEE 802.11-2007 standard that enables high-powered Wi-Fi equipment to operate on a co-primary basis in the 3650-3700 MHz band in the United States.[19]

SENSING-BASED SPECTRUM-SHARING TECHNOLOGIES

Sensing-based spectrum sharing approaches enable radio devices to identify unused spectrum by assessing and determining current use of a particular frequency through, for example, transmitter detection, cooperative sensing, or interference-based detection. Transmitter detection involves the capability of determining if a signal from another transmitter is using a frequency nearby by correlating a known signal with an unknown signal (matched filter detection), measuring signal energy (signal detection), or statistical means (cyclostationary feature detection or some other pattern recognition method). Cooperative sensing incorporates information about the spectral environment from multiple sensing devices to more accurately

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Docket No. 04-186, FCC 12-36 (2012), *available at* http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-12-36A1.pdf.

[16] *See* TV White Space Second Reconsideration Order and 47 C.F.R. Part 15, Subpart H (§§ 15.711, 15.717).

[17] *See* http://www.fcc.gov/encyclopedia/white-space-database-administration.

[18] *See* Wireless Operations in the 3650-3700 MHz Band, *Report and Order*, ET Docket No. 04-151, FCC 05-56 (2005). The FCC rules define a contention-based protocol as follows: "A protocol that allows multiple users to share the same spectrum by defining the events that must occur when two or more transmitters attempt to simultaneously access the same channel and establishing rules by which a transmitter provides reasonable opportunities for other transmitters to operate. Such a protocol may consist of procedures for initiating new transmissions, procedures for determining the state of the channel (available or unavailable), and procedures for managing retransmissions in the event of a busy channel." 47 C.F.R. § 90.7.

[19] IEEE 802.11y-2008 - IEEE Standard for Information technology-- Local and metropolitan area networks -- Specific requirements-- Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications Amendment 3: 3650-3700 MHz Operation in USA, *available at* http://standards.ieee.org/findstds/standard/802.11y-2008.html.

determine if spectrum is in use. Interference-based detection refers to sensing changes in the local noise floor to determine if additional traffic can be tolerated by primary users.[20]

Figure 2-1 provides an overview of sensing-based spectrum-sharing technologies.

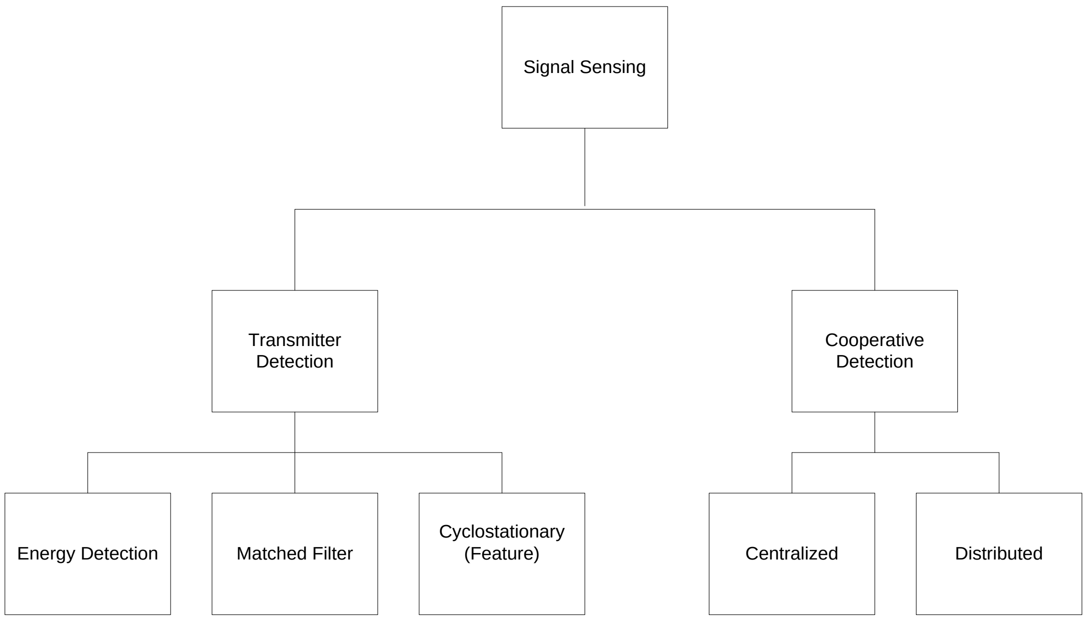

Figure 2-1. Overview of Sensing-Based Spectrum-Sharing Technologies

Energy Detection

Energy detection or threshold detection is the most common method to detect environmental signals because of the low computational complexity and implementation complexity.[21] It compares energy received within a given bandwidth (BW) with a pre-defined threshold. Observed energy less than the threshold implies that the frequency (or range of

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[20] Promoting More Efficient Use of Spectrum Through Dynamic Spectrum Use Technologies, *Notice of Inquiry*, ET Docket No. 10-237, FCC 10-198 at ¶ 20 (2010), *available at* http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-10-198A1.pdf.

[21] Rawat, G. Yan and C. Bajracharya, *Signal Processing Techniques for Spectrum Sensing in Cognitive Radio Networks*, International Journal of Ultra Wideband Communications and Systems Vol. x, No, x/x (2010) (*Techniques for Spectrum Sensing*) at 4; Mansi Subhedar and Gajanan Birajdar, *Spectrum Sensing Techniques in Cognitive Radio Networks: A Survey*, International Journal of Next-Generation Networks, Vol. 3, No, 2 (June 2011) (*Spectrum Sensing Techniques Survey*) at 42; Rania Mokhtar, Rashid Saeed, and Sabira Khatun, Fifth International Conference: Sciences of Electronic Technologies of Information and Telecommunications, *Spectrum Sensing and Sharing for Cognitive Radio and Advanced Spectrum Management*, Tunisia (Mar 22-26, 2009) (*SETIT 2009*) at 6; Danijela Cabric, Shridhar Mubaraq Mishra, and Robert W. Brodersen, Institute for Electrical and Electronics Engineers, Signals, Systems and Computers 2004 Conference Record of the Thirty-Eighth Asilomar Conference, *Implementation Issues in Spectrum Sensing for Cognitive Radios* (Nov 7-10 2004) (*Spectrum Sensing Implementation Issues*) at 774; Institute for Electrical and Electronics Engineers Communications Magazine, Stefan Geirhofer, Lang Tong, and Brian M. Sadler, *Dynamic Spectrum Access in the Time Domain: Modeling and Exploiting White Space* (*DSA White Space*) (May 2007) at 68.

frequencies) is not in use. This approach does not require any knowledge of the nature of the other transmitted signals. Under low signal-to-noise conditions, this technology may have difficulty differentiating environmental signals from background noise. The detection threshold is determined based on the operational scenario and technical parameters for the incumbent systems and technical and deployment characteristics of the new entrant. For example, the U-NII regulations specify different detection thresholds depending on the output power of the U-NII device.[22]

Matched Filter Detection

When the signal characteristics of other transmitted signals are known, the optimal detector in a stationary Gaussian noise environment is the matched filter because it maximizes the received signal-to-noise ratio.[23] While the main advantage of the matched filter approach is that it requires less time to achieve high processing gain due to coherency, it requires *a priori* knowledge of the incumbent spectrum user signal such as the modulation type and order, the pulse shape, and the packet format. If the characteristics of the signals being detected are not accurately defined, matched filter detection performs poorly. Matched filters are often used in signal detection for radar and communication systems.[24]

Cyclostationary (Feature) Detection

The cyclostationary (feature) detection approach couples modulated signals with sine wave carriers, pulse trains, repeating spreading, hopping sequences, or cyclic prefixes, which result in built-in periodicity.[25] These modulated signals are characterized as cyclostationary since their mean amplitude and autocorrelation exhibit periodicity. The mean amplitude of a modulated signal and the autocorrelation periodicity characteristics of a modulated signal are detected by analyzing a spectral correlation function. The main advantage of the spectral correlation function is that it differentiates the noise energy from modulated signal energy. A cyclostationary feature detector can perform better than an energy detector in discriminating

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[22] The existing U-NII detection thresholds were developed to protect ground-based and shipborne radar systems with specific operational scenarios and technical characteristics. NTIA performed a parametric analysis to determine the detection thresholds which considered combinations of the: number of U-NII devices, U-NII device antenna heights, and U-NII transmit bandwidths. Monte Carlo techniques were employed in the NTIA parametric analysis for the U-NII device locations, propagation losses, U-NII device antenna heights and other non-terrain specific losses. Changes in the operational scenarios and technical characteristics for the radar systems or the technical and deployment parameters for the U-NII devices would result in different detection thresholds.

[23] Techniques for Spectrum Sensing at 5; Spectrum Sensing Techniques Survey at 43; SETIT 2009 at 6; Spectrum Sensing Implementation Issues at 774.

[24] Merrill I. Skolink, Introduction to Radar Systems, Second Edition, at 369; Leon W. Couch II, Digital and Analog Communication Systems, Fourth Edition, at 547.

[25] Institute for Electrical and Electronics Engineers Communications Society, Takeshi Ikuma and Mort Naraghi-Pour, *A Comparison of Three Classes of Spectrum Sensing Techniques* (2008) at 5; Techniques for Spectrum Sensing at 5; Spectrum Sensing Techniques Survey at 44; DSA White Space at 68.

against noise due to its robustness to the uncertainty in noise power. However, cyclostationary detection is computationally complex and can require significantly longer observation times as compared to energy or matched filter detection approaches.

Cooperative Detection

Cooperative centralized detection collects sensing data from multiple, geographically dispersed devices and identifies potentially available spectrum within the area where the sensors were located.[26] In contrast to using a single sensor, this approach reduces the probability of missing information regarding local spectrum utilization; however, for a large number of devices the sensing data collected may require larger bandwidth. Cooperative distributed detection devices share information with each other, but make their own estimations regarding spectrum use at a given location. Distributed sensing has the advantage that it does not need a backbone infrastructure. The network overhead information increases the requirement for more bandwidth to share the sensing data among the cooperative nodes in the network.

Summary of Sensing-Based Spectrum Sharing Technologies

Each approach presented has advantages and disadvantages in signal detection, which are summarized in Table 2-1, where the following performance parameters are compared:

- Execution Time. The ideal signal detector would work in real-time with an execution time is as short possible.
- Noise Rejection. The ability to be immune to Gaussian noise.
- Knowledge A-priori. How much transmitted signal information is necessary to detect the signal.
- Computational Complexity. Capacity calculation required to detect a signal.
- Interference Rejection. The ability to be immune to signals other than Gaussian noise.

Table 2-1. Summary of Sensing-Based Spectrum-Sharing Technologies

Approach	Execution Time	Noise Rejection	Knowledge A-Priori	Computational Complexity	Interference Rejection
Energy Detection	High	Low	None	Low	Low
Matched Filter	Medium	Medium	High	Low	High
Cyclostationary	Low	High	Medium	High	High

[26] Techniques for Spectrum Sensing at 6; Spectrum Sensing Techniques Survey at 45; SETIT 2009 at 7.

GEO-LOCATION-BASED SPECTRUM-SHARING TECHNOLOGIES

A database containing information about incumbent spectrum users, when combined with a geo-location system such as the Global Positioning System and an interference-free location-data communications link, provides a mechanism to facilitate spectrum sharing with incumbents operating at fixed or known locations with known technical parameters.[27] This approach requires the development of a database infrastructure, use of a management control system (*e.g.*, with the ability to send timely and accurate information to remote devices), sharing of technical and deployment parameters for specific systems operating in the frequency bands, and an over-the-air system identification. Geo-location spectrum-sharing technologies can be used in conjunction with a well maintained, current database to define geographic areas where device operation will and will not be permitted, or where limitations should be placed on the operating parameters to enable spectrum sharing (*e.g.*, reduction of power).

The information needed for the database (specific technical parameters, usage contours, protection contours) would have to be pre-determined. A determination is needed as to whether the database can provide accurate information regarding spectrum use on a real-time basis or at specified time intervals. Questions related to building and administering the database and handling sensitive or classified system parameters would have to be addressed. Procedures for ensuring devices have appropriate authorization to access the database would also have to be developed. To date, geo-location based spectrum-sharing technology has primarily been used to facilitate sharing with fixed systems. This technology has not been deployed with mobile systems, such as the transportable ground-based, shipborne, and airborne radar systems that operate in the 5350-5470 MHz and 5850-5925 MHz bands.

In examining new approaches to spectrum allocation, the PCAST recommended implementing a real-time or near real-time dynamic database, Spectrum Access System (SAS) to govern shared access to federal frequency bands.[28] The PCAST believes that shared use can be coordinated primarily by registering and communicating with a management database, similar to the White Space Databases certified by the FCC. The SAS would serve as an information and control clearinghouse for band-by-band registrations and conditions of use that would apply to all users. The database would enable a number of distinct operational functions.[29] For example, devices would be certified for secondary and opportunistic access only if they could connect to the database and periodically seek renewed transmit permission and/or terms of use updates required for each band authorized. The SAS would require automatic connection to a database to ensure that no devices are operating under out-of-date terms of use or without the capacity to be denied access to a particular band when necessary. The system of certification, registration, and

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[27] CSMAC Subcommittee Final Report at Section 3.3.

[28] PCAST Report at 24.

[29] *Id*. at 101.

authentication through a geo-location database would also facilitate enforcement, since the identity, manufacturer, and recent location(s) of errant devices could be readily determined from transactional data collected by the database.

BEACONING/PILOT CHANNEL SPECTRUM-SHARING APPROACHES

In a beacon spectrum-sharing approach, a new entrant's transceiver must have the ability to receive a control signal sent continuously by the incumbent systems at times when transmissions by the new entrant are permitted. The new entrant may not commence transmissions if beacon signals are not received, and if any beacon signal is present but then stops while the new entrant is transmitting, transmissions must cease within a specified time interval. The beacons could be a radio frequency signal sent by incumbents on designated control frequencies, or they may be signals received over a physical connection such as fiber, copper, or coaxial cable. Transmission by the new entrant would cease if any beacon signal suffers from unfavorable propagation conditions or the physical connection is lost such that the beacon signals are not properly received by the new entrant. In other words, the incumbent has "fail-safe" protection against harmful interference, because if the new entrant cannot hear the beacon signal, it must cease transmission.

The Institute of Electrical and Electronics Engineers developed a standard that defines the air interface (protocol and data formats) for communication devices that form a beaconing network that offers an enhanced protection method to help prevent harmful interference with low-power, licensed devices operating in television broadcast bands.[30] The beacons transmit identifiable synchronization bursts as well as, optionally, information about locations and operational parameters of the protected systems.

Several of the systems operating in the 5350-5470 MHz and 5850-5925 MHz bands operate in sensitive or classified locations, resulting in an operational security risk if this spectrum-sharing technology is employed. Additionally, the implementation of this sharing technique would require the modification of all incumbent systems to include the beacon transmitter.

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30 IEEE Std 802.22.1-2010, IEEE Standard for Information Technology – Telecommunications and information exchange between systems Local and metropolitan area networks – *Specific requirements Part 22.1: Standard to Enhance Harmful Interference Protection for Low-Power Licensed Devices Operating in the TV Broadcast Bands* (Nov. 1, 2010).

U-NII DEVICE SPECTRUM-SHARING TECHNOLOGIES

The U-NII devices currently authorized to operate in the 5250-5350 MHz and 5470-5725 MHz bands employ TPC and DFS capabilities, which are discussed in the next section.

DFS is a form of sensing-based sharing technology that requires signal detection where knowledge of certain parameters of the radar signal such as pulsewidth, pulse repetition interval, and the number of pulses per burst are used to improve signal detection.[31] This study considered both signal sensing and geo-location spectrum-sharing technologies in connection with the potential introduction of U-NII devices in the 5350-5470 MHz and 5850-5925 MHz bands. These spectrum-sharing technologies are already in use by unlicensed devices. On the other hand, even though cooperative sensing between U-NII access points and client devices is feasible, sharing sensing data among different unlicensed devices has not been addressed in the industry standards bodies for unlicensed devices. Beaconing and pilot channel approaches, while the subject of industry standards in connection with other frequency bands and applications, do not appear to be employed at this time. Accordingly, NTIA considered the spectrum-sharing technologies shown in Table 2-2 in its qualitative evaluation.

Table 2-2. U-NII Device Spectrum-Sharing Technologies

Spectrum-Sharing Technology	Description
Energy Detection	A spectrum-sharing technology where the detection level is defined by detecting a received signal strength in a reference bandwidth that is greater than a specified threshold
Signal Detection	A spectrum-sharing technology that employs a combination of threshold detection and signal parameter pattern recognition
Energy Detection and Geo-Location	A spectrum-sharing technology that employs a combination of threshold detection and geo-location/database capability
Signal Detection and Geo-Location	A spectrum-sharing technology that employs a combination of signal detection and geo-location/database capability

ADDITIONAL SAFEGUARDS TO FACILITATE SPECTRUM-SHARING ARRANGEMENTS

Where the spectrum-sharing technologies in Table 2-2 may not adequately address the identified risk to incumbent systems, NTIA, as part of its upcoming quantitative study, will identify additional regulatory or technical approaches that could facilitate sharing arrangements. These include assumptions or restrictions such as power limits, indoor/outdoor deployment, TPC requirements, and policy-based device management.

[31] The IEEE Standard Dictionary of Electrical and Electronics Terms (ANSI/IEEE Std 100-1988) defines pulsewidth as the time interval between half-power points on the trailing and leading edges of the pulse and the pulse repetition interval as the time duration between successive pulses.

SECTION 3. U-NII DEVICE REGULATIONS AND STANDARDS

INTRODUCTION

This section provides an overview of FCC regulations and industry standards related to U-NII devices. The existing FCC regulations for U-NII DFS-enabled devices were developed jointly between NTIA, the FCC, the federal agencies, and industry representatives over an approximate five-year time period. During that time, the agencies and industry worked together on analysis and measurements (laboratory and field) in support of the final rules and the certification measurement procedures that the FCC adopted.[32]

OVERVIEW OF FCC PART 15 REGULATIONS FOR THE 5 GHZ BAND

Under its Part 15 Rules, the FCC authorizes U-NII devices to operate in the 5150-5350 MHz and 5470-5825 MHz bands.[33] Table 3-1 summarizes the maximum allowable equivalent isotropically radiated power (EIRP), DFS requirements, and limitations on operational deployment for each frequency band authorized for U-NII device operation.

Table 3-1. Summary of U-NII DFS Technical and Operational Parameters

Frequency Band (MHz)	U-NII Band Identifier	Maximum Allowable EIRP (dBm)	DFS Required	Operational Deployment
5150-5250	UNII-1	23	No	Indoor Only
5250-5350 and 5470-5725[34]	UNII-2	30	Yes	Indoor and Outdoor
5725-5825[35]	UNII-3	53	No	Indoor and Outdoor

The Part 15 U-NII rules specify DFS detection thresholds based on the EIRP of the device: -64 dBm for devices with a maximum EIRP of greater than 23 dBm and -62 dBm for devices with a maximum EIRP of less than 23 dBm.[36] These detection thresholds are applicable to the DFS channel availability check and in-service monitoring functions described below:

Channel Availability Check - a check where the U-NII device listens on a particular channel to identify whether there is a radar operating on that radio channel.

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[32] The FCC U-NII regulations were developed over a five year timeframe which began in March 2002 and ended with the FCC issuing compliance measurement procedure in April 2007. *See* Office of Engineering and Technology Laboratory Division Knowledge Database, Publication Number: 905462 (Apr. 17, 2007), *available at* https://apps.fcc.gov/kdb/GetAttachment.html?id=PIDuzGyOggplxY%2F09X8mgA%3D%3D.

[33] *See* 47 C.F.R. Part 15, Subpart E.

[34] U-NII devices operating in these bands at peak power are required to reduce by the amount in dB that the directional gain exceeds 6 dBi. *See* 47 C.F.R § 15.407(a)(1).

[35] U-NII devices operating in this band can employ a directional antenna with a maximum gain of 23 dBi without any reduction in the peak transmitter output power. *See* 47 C.F.R § 15.407(a)(3).

[36] *See* 47 C.F.R. § 15.407(h)(2).

In-Service Monitoring - a mechanism to check a channel in use by the U-NII device for the presence of a radar.

The rules establish a 60-second time period for the channel availability check time. The radio frequency (RF) channel move time is defined as a period of 10 seconds during which all transmissions on a RF channel must cease. Transmissions during this period consist of normal traffic for typically less than 100 milliseconds and a maximum of 200 milliseconds after detection of a radar signal. Intermittent management and control signals can be sent during the remaining time to facilitate vacating the operating RF channel. The aggregate time of the intermittent management and control signals is typically less than 20 milliseconds. A RF channel on which a radar was detected either during the channel availability check or in-service monitoring is subject to a 30 minute non-occupancy period.[37]

The current regulations define two types of U-NII devices: access point devices and client devices. Access point devices can initiate a network and client devices cannot transmit until an enabling signal is received from an access point. In the current implementation, DFS functionality is delegated to access point devices.

U-NII devices operating in the 5250-5350 MHz and 5470-5725 MHz bands with an EIRP of greater than 27 dBm must employ a TPC mechanism. The FCC also has certification measurement procedures for U-NII devices operating in the 5250-5350 MHz and 5470-5725 MHz bands, including test waveforms based on the characteristics of representative radar systems.[38] Appendix A provides an overview of the radar signal parameters used in FCC certification of U-NII devices.

INDUSTRY STANDARDS

The IEEE 802.11h[39] and 802.11n[40] standards govern wireless networking transmission methods for unlicensed devices in the 5 GHz bands. IEEE 802.11ac is a standard under development, which will provide higher throughput in the 5 GHz bands. It will enable multi-station throughput of at least 1 gigabit per second and a maximum single link throughput of at least 500 megabits per second, by using wider RF bandwidths (80 MHz or 160 MHz), more data streams (up to eight), and high-density modulation (up to 256 Quadrature Amplitude

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[37] *Id.*

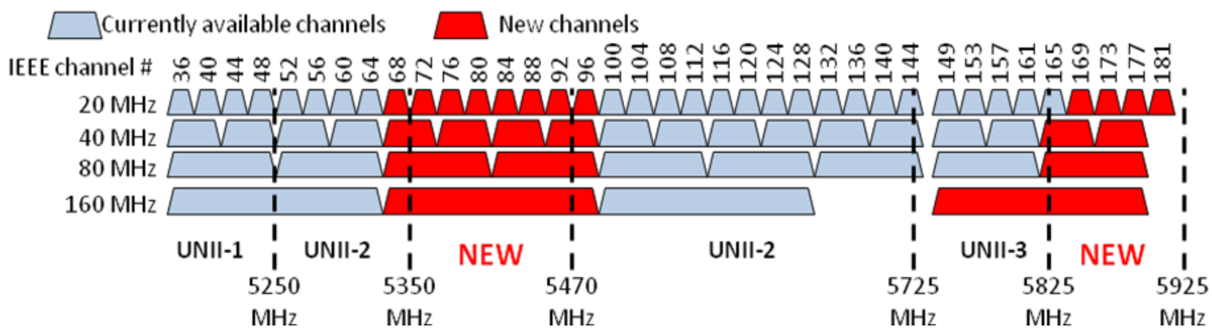
[38] *See* U-NII Reconsideration Order.

[39] IEEE 802.11h, *IEEE Standard for Information technology – Telecommunications and information exchange between systems – Local and metropolitan area networks – Specific requirements Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications Amendment 5: Spectrum and Transmit Power Management Extensions in the 5 GHz band in Europe* (2003).

[40] IEEE 802.11n, *IEEE Standard for Information technology – Telecommunications and information exchange between systems – Local and metropolitan area networks – Specific requirements Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications Amendment 5: Enhancements for Higher Throughput* (2009).

Modulation). U-NII devices developed on the 802.11h and 802.11n standards have RF bandwidths of 20 MHz and 40 MHz, respectively.

As shown in Figure 3-1 below, the wider RF bandwidths supported by the IEEE 802.11ac standard require large blocks of contiguous spectrum.[41]



UNII-1: 5150-5250 MHz band

UNII-2: 5250-5350 MHz and 5470-5725 MHz band

UNII-3: 5725-5825 MHz band

Figure 3-1. Currently Available and New 5 GHz Channels

While the currently available channels support a number of combinations of these wider RF bandwidth channels, expanding the amount of spectrum authorized for U-NII device operation in the 5 GHz frequency range will increase the contiguous spectrum available to accommodate broadband applications. As shown in Figure 3-1, additional unlicensed use of 5.35-5.47 GHz and 5.85-5.925 GHz would allow nine 80 MHz channels and four 160 MHz channels (shown in red).

The FCC has provided guidance for testing of IEEE 802.11ac and pre-ac devices for compliance with Section 15.247 and 15 subpart E (Section 15.401 through Section 15.407) of their rules.[42] All transmissions above 5.725 GHz must be under Section 15.407 whenever operating on a channel where the emission bandwidth crosses 5.725 GHz. The part of the transmission that is below 5.725 GHz is in a band that is permitted only under the Section 15.407 rules. The part of the transmission that is above 5.725 GHz is in a band that could normally be permitted under either Section 15.247 or Section 15.407, but because part of the signal is covered only by Section 15.407, the entire signal must comply with Section 15.407.

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[41] This figure was presented in https://mentor.ieee.org/802.11/dcn/12/11-12-1159-03-00ai-masers-slaves-and-clients.pptx.

[42] *See* Office of Engineering and Technology Laboratory Division Knowledge Database, Publication Number: 644545 (June 7, 2012).

EXISTING RADAR INTERFERENCE ISSUES

In 2009, the Federal Aviation Administration (FAA) became aware of interference to its Terminal Doppler Weather Radar (TDWR) systems that operate in the 5600-5650 MHz band. These radars provide quantitative measurements of gust fronts, wind shear, microbursts, and other weather hazards for improving the safety of operations in and around 45 major airports.

At the request of the FAA, NTIA and the FCC conducted an interference investigation that concluded interference was being caused by U-NII devices and unlicensed devices operating in the 5725-5850 MHz band pursuant to Section 15.247 of the FCC's rules with building-mounted, high-gain antennas (unobstructed view to TDWR) for outdoor point-to-point communications links.[43] There have not been any cases of TDWR interference identified for other unlicensed device applications. The investigation identified the following causes of interference:

- unlicensed device did not employ DFS and was modified to operate in the 5470-5725 MHz band;
- U-NII device DFS functionality was available but was disabled by the operator;
- U-NII device DFS functionality performed properly, causing the device to move to an adjacent channel, but still caused interference;
- unlicensed device was not certified by the FCC;
- unlicensed device was not certified by the FCC to operate in the bands authorized for U-NII devices (*e.g.*, Section 15.247);
- unlicensed device and antenna combinations were not certified by the FCC;
- U-NII device complied with FCC DFS certification requirements but failed to detect TDWR; and
- U-NII DFS compliance test waveforms did not accurately represent all of the TDWR modes of operation.

Results of this investigation led to the FCC to temporarily suspend granting new equipment authorizations for access point devices in mid-2009 while it worked on ways to mitigate these problems. On October 8, 2009, the FCC introduced interim measures that

[43] NTIA Technical Report TR-11-473, *Case Study: Investigation of Interference into 5 GHz Weather Radars from Unlicensed National Information Infrastructure Devices, Part I* (Nov. 2010), *available at* http://www.its.bldrdoc.gov/publications/2548.aspx (*NTIA Case Study Part I*); NTIA Technical Report TR-11-479, *Case Study: Investigation of Interference into 5 GHz Weather Radars from Unlicensed National Information Infrastructure Devices, Part II* (July 2011), *available at* http://www.its.bldrdoc.gov/publications/2554.aspx (*NTIA Case Study Part II*); and NTIA Technical Report TR-12-486, *Case Study: Investigation of Interference into 5 GHz Weather Radars from Unlicensed National Information Infrastructure Devices, Part III* (June 2012) , *available at* http://www.its.bldrdoc.gov/publications/2677.aspx (*NTIA Case Study Part III*).

restricted the approval of access points in the 5470-5725 MHz band to devices operating indoors and placed restrictions on the approval of certain U-NII access point devices.[44]

Subsequently, the FCC has allowed outside operation with the following restrictions: U-NII devices must be professionally installed; operations are not allowed in the 5600–5650 MHz band (TDWR frequencies); and U-NII devices within 35 kilometers of a TDWR location shall be separated by at least 30 MHz (center frequency-to-center frequency) from the TDWR operating frequency.[45] The Wireless Internet Service Provider Association created the U-NII Device Interference Advisor (UDIA), an online database and registry containing detailed information about TDWR systems and registered U-NII devices.[46] This tool allows a network operator or installer to search and confirm if their device is operating within 35 km proximity of TDWR site(s) and voluntarily register certain technical information into the online database.[47] Federal government personnel can search this single resource to quickly identify registered network operators and determine which operators may be interfering with TDWR devices. Access to registration data is restricted to the FCC, the FAA, and to individual network operators.

The FCC has continued to work with industry, the FAA, and NTIA to address interference to TDWR systems. However, instances of interference to TDWRs continue. A majority of the fully documented interference cases have involved the operation of high-power systems deployed with high-gain antenna. A vast majority are due to unauthorized operation of devices rather than failure of a properly operating U-NII device. NTIA is not aware of any documented cases of harmful interference from U-NII devices used for low power applications such as laptop computers, tablets, or smart phones.

The interference to TDWR demonstrates the importance of the FCC certification and enforcement processes that must be taken into consideration to effectively preclude harmful interference if U-NII device operations are authorized in the 5350-5470 MHz and 5850-5925 MHz bands. NTIA anticipates that a forthcoming FCC proceeding will address certification and enforcement issues for U-NII devices that were identified as part of the TDWR interference investigation.

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[44] As a result of the TDWR interference investigation the FCC has taken a number of enforcement actions where the operators had caused interference or used unauthorized equipment. A list of the FCC enforcement activities is publicly available at http://www.fcc.gov/encyclopedia/weather-radar-interference-enforcement.

[45] FCC Office of Engineering and Technology, Approval of DFS U-NII Devices v01, KDB 443999 D01 (Oct. 14, 2010), *available at* http://apps.fcc.gov/oetcf/kdb/forms/FTSSearchResultPage.cfm?switch=P&id=41732.

[46] The Wireless Internet Service Providers Association and Spectrum Bridge Inc. Press Release, *Spectrum Database Solution Enables Access to 5GHz Spectrum Previously Unavailable Due to Interference Issues* (July 27, 2010), *available at* http://www.spectrumbridge.com/Libraries/Press_Releases/Spectrum_Database_Solution_Enables_Access_to_5GHz_Spectrum_Previously_Unavailable_Due_to_Interference_Issues_July_27_2010.sflb.ashx.

[47] The UDIA database is available at http://www.spectrumbridge.com/udia/search.aspx.

In an earlier effort culminating with the publication of a Technical Report in 2006, NTIA examined critical questions regarding the robustness of radar receiver performance in the presence of RF interference, especially at low levels.[48] The report concluded that, based on wide-ranging interference measurements performed on many representative radar receivers, the loss of targets at low interference levels was "insidious" as there was no overt indication to the radar operators or even to sophisticated radar software that losses were occurring. According to this report, it was unlikely that such interference would be reported to spectrum management authorities, even when radars experienced serious performance degradation due to low-level interference, because the operators "would probably not be aware that targets that should otherwise have been detected were missing, nor that any interference was occurring." The loss of targets due to interference was not directly related to the distance of the targets from the radar.

[48] NTIA Technical Report TR-06-444, *Effects of RF Interference on Radar Receivers* at 137 (Sept. 2006), *available at* http://www.its.bldrdoc.gov/publications/2481.aspx (*Technical Report TR-06-444*).

SECTION 4. EVALUATION OF RISKS TO FEDERAL SYSTEMS OPERATING IN THE 5350-5470 MHZ BAND

INTRODUCTION

This section describes the risks to federal systems and possible mitigation strategies associated with allowing U-NII devices to operate in the 5350-5470 MHz band.

OVERVIEW OF SYSTEMS OPERATING IN THE 5350-5470 MHZ BAND

The 5350-5470 MHz band is allocated for both federal and non-federal use on a primary basis. The federal allocations on a primary basis are to the Earth exploration-satellite, space research, and radiolocation services. Additionally, federal and non-federal primary allocations include aeronautical radionavigation in the 5350-5460 MHz band and radionavigation in the 5460-5470 MHz band. An overview of the federal systems operating in the 5350-5470 MHz band is provided below. Appendix C provides a more detailed description of DoD systems operating in the band.

Radar Systems

The DoD uses the 5350-5470 MHz band for a wide variety of applications. Range and tracking radar systems are the prime tracking system for range safety that is essential for protection of life and property when testing non-cooperative targets, which include many weapon systems tested or used in training on DoD test and training ranges. Tactical anti-air warfare radar systems are part of an advanced ground-based air defense missile system. Other tactical radars operating in this band include shipborne radars for surface search, navigation, and weapons fire control. Airborne weather navigation radars for storm avoidance also operate in this band. These military radars have the operational capability to tune across the entire 5250-5725 MHz frequency range and can either operate on a fixed frequency or employ frequency hopping techniques. In the past, these radars have operated on or near military installations. However, situations may arise where these radars have to be used more widely in support of homeland security. One of the areas of concern in assessing interference to military radars stems from future radar deployments and the expanding role of military radars in support of homeland defense. This expanded role could result in a requirement to deploy military radars in cities and metropolitan areas where unlicensed devices will have their highest usage.

The Coast Guard also operates shipborne radars, which are used by National Security Cutters while performing the following missions: defense readiness; drug interdiction; other law enforcement actions such as patrolling fisheries, ports, waterways, and coastal areas; search and rescue; and marine environmental protection. Radar systems operating in this band provide ships with surface search and navigation capabilities and tracking services, particularly during inclement weather. These radars are vital sensors for safe navigation of waterways.

The Federal Aviation Administration mandates that aircraft operating under 14 Code of Federal Regulations (14 C.F.R.) Part 121 and certain aircraft operating under 14 C.F.R. Parts 91 and 135 carry weather radars to provide the pilots with weather information for safe aeronautical navigation. Some of the early radar equipment installed on these aircraft still use the 5350-5470 MHz frequency band. Theses radars can be used at various altitudes for weather as well as microburst detection.

In addition to the radar systems used by the DoD, several other agencies operate radar systems in the band. The National Aeronautics and Space Administration (NASA) uses this band for test and launch range instrumentation radars to track rockets, missiles, satellites, launched vehicles, and other targets. These radars are usually the prime coverage system for range safety. Range instrumentation radar transponders also operate in the band to enhance radar tracking of low cross-section aircraft and missiles and systems under test. The National Oceanic and Atmospheric Administration operates radar systems in the band on "Hurricane Hunter" aircraft. The Department of Energy operates radar systems and associated transponders in the band at two specified test ranges in the United States.

Airborne Systems

The DoD operates several airborne systems in this band. Aeronautical telemetering mobile stations in this band for transmit data directly related to the airborne testing of vehicles or major components such as rockets, missiles, and vehicles.[49] This band also supports the testing of unmanned aircraft system (UAS) datalinks from aircraft-to-ground and from ground-to-aircraft. The UAS datalink provides command and control information from the ground control station (GCS) to the UAS using the command link. Payload data and UAS status information are transmitted from the UAS to the GCS using a return link. The command link, a ground data terminal transmitter, operates at 5625-5850 MHz and the return link (UAS transmitter) transmits at 5250-5475 MHz. The Army, Navy, and Air Force operate UAS in the 5 GHz frequency range for intelligence, surveillance, and reconnaissance; combat search and rescue; convoy and raid over-watch; and real-time full-motion video for target development. These agencies conduct test and training in support of these missions at sites in the United States. In addition, sense-and-avoid radar systems are being developed to permit autonomous operation of unmanned aircraft, and diagnostic radars are being developed to test low-observable materials. The Department of Homeland Security (DHS) also operates UAS in this band for drug interdiction and border surveillance operations. The NASA also operates a limited number of systems in the 5350-5470 MHz band that are used for downlink transmissions of data to ground control receivers.

Spaceborne Synthetic Aperture Radar Systems

NASA, in a joint venture with the French agency, Centre National d'Etudes Spatiales, operates a space-based altimeter system in the 5140-5460 MHz band that is used to obtain measurements of the Earth's ocean surface height.

[49] There is no frequency allocation for UAS operations in the 5350-5470 MHz band; however, NTIA has authorized federal agencies to operate UAS systems throughout the United States.

Synthetic aperture radar (SAR) systems in the 5350-5470 MHz band perform space-based observations and measurements of surface topography, soil moisture, and sea surface height. Active sensing is the measurement on board a spacecraft of signals transmitted by a sensor and then reflected, refracted, or scattered by the Earth's surface or its atmosphere. The higher quality data collected using wideband SARs allow scientists to gain new insight into the prediction of climatic changes. These wideband SARs also provide the higher resolution necessary for commercial applications, such as high-resolution surface mapping.[50]

Canada operates an Earth exploration-satellite, known as RADARSAT, in the 5350-5470 MHz band to provide mission critical data in support of national security, public safety, law enforcement, and civilian applications in Canada and the United States.[51] These applications include disaster management; response and recovery for safety of life; ice monitoring; surveillance including maritime domain awareness; oil spill response; hydrology; mapping; geology; safety of navigation; agriculture; and forestry. Federal agencies use the data collected by spaceborne synthetic aperture radar systems. For example, the United States Coast Guard International Ice Patrol uses RADARSAT data operationally to detect and track icebergs. In assessing the feasibility of allowing U-NII device operation in the 5350-5470 MHz band, NTIA will examine the potential impact to the RADARSAT and other spaceborne synthetic aperture radar systems as part of this qualitative study.

IDENTIFICATION OF RISKS TO SYSTEMS OPERATING IN THE 5350-5470 MHZ BAND

This report identifies risks based on the potential for interference to federal systems if U-NII devices are allowed to operate in the 5350-5470 MHz band. The technical and operational characteristics of federal systems and/or the technical and deployment parameters of the U-NII devices affect the risk. These risks also arise from the premise that the FCC may authorize U-NII DFS devices using its current regulations. Where feasible, the federal agencies conducted preliminary analyses using the existing U-NII regulations and estimated deployment parameters to quantify the interference risks. Table 4-1 provides an overview of the risk elements and suggested mitigation strategies for each category of system associated with allowing U-NII device operation in the 5350-5470 MHz band.

50 For example, wide bandwidth SARs can precisely map the boundary of oil spills to a resolution of 1 meter.

51 *See* letter from Helen McDonald, Senior Assistant Deputy Minister, Spectrum, Information Technologies and Telecommunication, Industry Canada to Karl Nebbia, Associate Administrator, Office of Spectrum Management, NTIA (July 6, 2012). A copy of this letter is available upon request.

Table 4-1. Overview of Risk Elements and Suggested Mitigation Strategies Associated with the 5350-5470 MHz Band

System Category	Description of Risk Element	Suggested Mitigation Strategy
Radar	Risk Element 1 - Changes in radar signal parameters may impact U-NII device detection of radar systems.	- Review radar signal parameters used in the development of existing regulations and assess whether existing U-NII device spectrum sharing technologies can be used to protect current and future radar systems.
	Risk Element 2 - Changes in U-NII device deployment and technical parameters may result in harmful interference.	- Update U-NII device deployment and technical parameters used in quantitative analysis.
	Risk Element 3 - Existing U-NII regulations may not adequately protect current and future radar systems from serious degradation.	- Identify new sharing scenarios for current and future radar systems. - Perform quantitative analysis to evaluate current DFS regulations.
	Risk Element 4 - Changes to existing U-NII DFS detection parameters may not protect current and future radar systems from serious degradation.	- Develop representative test signals for laboratory measurements to verify DFS detection capabilities. - Perform laboratory measurements using prototype devices and simulated radar signals. - Perform field measurements using actual radar signals to verify laboratory measurements. - Modify existing DFS regulations based on the results of quantitative analysis and measurements.
	Risk Element 5 – Existing U-NII regulations may introduce “hidden node” interference that seriously degrades performance.	- Examine the conditions under which “hidden node” interference exists. - Modify existing U-NII device regulations as needed to resolve “hidden node” interference.
	Risk Element 6 – U-NII devices operating on an adjacent channel may cause harmful interference to radar systems.	- Perform quantitative analysis to assess the impacts of adjacent channel interference. - Perform measurements to evaluate different options for addressing adjacent channel interference. - Modify existing U-NII device regulations based on the results of quantitative analysis and measurements.
	Risk Element 7 – Radar receiver interference protection criteria used to develop existing U-NII DFS regulations may not address low-level interference effects.	- Evaluate the interference protection criteria used in the development of the current DFS regulations to determine if they adequately protect radar systems from low-level interference effects. - If necessary revise the interference protection criteria to address low-level interference effects.
	Risk Element 8 – Channel response time requirements in the current DFS regulations may not be adequate to protect all radar system operational scenarios.	- Perform analysis to determine if it is necessary to add a channel response time to the DFS regulations to protect radar systems operating in different scenarios. - Modify the existing U-NII DFS device certification test procedures based on the results of the analysis.

Table 4-1. Overview of Risk Elements and Suggested Mitigation Strategies Associated with the 5350-5470 MHz Band (Continued)

System Category	Description of Risk Element	Suggested Mitigation Strategy
Airborne Systems	Risk Element 1 - Existing U-NII regulations were not developed to detect airborne signals.	- Develop representative technical parameters and sharing scenarios to examine impact to ground-based and airborne operations. - Perform quantitative analysis to evaluate whether current DFS regulations protect airborne operations.
	Risk Element 2 - U-NII signal detection technologies may not be capable of detecting airborne signals resulting in serious performance degradation.	- Determine if current signal detection techniques for sharing among U-NII devices can be used or adapted to detect ground-based and airborne signals.
	Risk Element 3 - Current U-NII regulations were not developed to protect systems where the transmitter and receiver are not co-located.	- Examine the conditions under which a "hidden node" problem exists. - Identify any possible sharing approaches for more detailed quantitative analysis.
	Risk Element 4 - Changes to U-NII DFS detection parameters may not protect airborne operations from performance degradation.	- Develop representative test signals for laboratory measurements to verify DFS detection capabilities. - Perform laboratory measurements using prototype devices and simulated airborne signals. - Perform field measurements using actual airborne signals to verify laboratory measurements. - Modify existing DFS regulations based on the results of the analysis and measurements.
SAR	Risk Element 1- Existing U-NII regulations were not developed to protect spaceborne receivers.	- Perform quantitative analysis to assess the potential interference impact to SAR receivers. - Determine if limitations on U-NII device deployment and technical parameters will mitigate interference to SAR receivers.

DESCRIPTION OF RISKS TO RADAR OPERATIONS IN THE 5350-5470 MHZ BAND

Risk Element 1 - Changes in Radar Signal Parameters May Impact U-NII Device Detection of Radar Systems

The following paragraphs evaluate the impact on different spectrum-sharing technologies related to the risk associated with new signal parameters of federal radar systems.

Energy Detection. This spectrum-sharing technology performs signal sensing during the channel availability check and in-service monitoring functions using a dedicated listen time (*e.g.*, no data transmissions). A dedicated listen time eliminates reliance on using the specific parameters of the radar signal (*e.g.*, pulse width, pulse repetition interval) to detect the presence of a radar system. Since this spectrum-sharing technology does not require knowledge of radar signal characteristics, it will minimize the risk associated with changes in the signal parameters that can impact the detection of ground-based, airborne, and shipborne radar systems operating in the 5350-5470 MHz band. However, recently fielded and in-development radar systems that include low-power modes or are designed to avoid detection to meet their mission requirements may present challenges for this spectrum-sharing technology. If set too low, the U-NII devices may be unable to determine the difference between a radar and another U-NII device.

Matched Filter Detection. Matched filter detection technology requires prior knowledge of the characteristics of radar signals to be effective. Defining the specific characteristics for federal radar signals is not possible because this would limit future radar system design. To allow greater flexibility for future radar designs, signals must be defined in terms of ranges of parameters as in the existing U-NII regulations described in Appendix A. Matched filter detection may not be effective for sharing between U-NII devices and federal radar systems in the 5350-5470 MHz band given that the exact characteristics of the radar signals cannot be rigidly specified and are subject to change.[52] This spectrum-sharing technology will not address the risk associated with changes in the radar signal parameters that can impact detection of radar systems.

Signal Detection. Signal detection employs a combination of threshold detection and signal parameter pattern recognition. This spectrum-sharing technology is currently employed by U-NII DFS devices operating in the 5250-5350 MHz and 5470-5725 MHz bands where radar signal parameters such as pulse width, pulse repetition interval, and the number of pulses per burst are known and can be used to improve signal detection. Using this technology, devices perform signal sensing in the quiet periods between data transmissions as described in Annex 4 of Recommendation ITU-R M.1652.[53] It is highly dependent on the transmission characteristics of the

[52] Changes in mission requirements and the targets to be detected can result in the development of new radar signals. A spectrum sharing technology must be adaptable to these signals changes and cannot constrain the development of future radar systems.

[53] Recommendation ITU-R M.1652, *Dynamic Frequency Selection (DFS) in Wireless Access Systems Including Radio Local Area Networks for the Purpose of Protecting the Radiodetermination Service in the 5 GHz Band* (2003).

U-NII devices and the parameters defining the radar signals. Any changes to the radar signal parameters described in Appendix A and/or U-NII device transmission characteristics could impact the detection capabilities of the U-NII devices and increase the potential for interference to federal radar systems. The transmission characteristics of the higher data rate signals envisioned under the IEEE 802.11ac standard will tend to reduce the time during which a U-NII device is sensing. This reduced sensing time, in conjunction with radar systems that employ pulsed signals with narrower pulsewidths and/or lower pulse repetition rates, will impact U-NII device detection capabilities and needs to be analyzed in more detail to determine if this spectrum-sharing technology addresses the identified risk.[54] In addition, recently fielded and in-development radar systems that include low-power modes or are designed to avoid detection to meet their mission requirements, may present challenges for this spectrum sharing technology.

Geo-Location. FCC regulations do not require U-NII DFS devices to implement geo-location technology for sharing with federal radar systems operating in the 5250-5350 MHz and 5470-5725 MHz bands.[55] However, the recent approval by the FCC of TVBDs that use geo-location technology with a database demonstrates this spectrum-sharing technology could open up new sharing opportunities with systems operating at fixed locations (*e.g.*, military bases, test facilities). Since the transmitter and receiver for a radar system are at the same location, geo-location technology could be effective, particularly for fixed ground-based radar systems. Geo-location technology may not be particularly effective for transportable ground-based radar systems or airborne radar systems that may be authorized to operate nationwide and shipborne radar systems that can operate anywhere along the U.S. coast.

To implement geo-location technology, a database of radar locations or geographic locations around which protection distances and/or frequency restrictions are established could be developed.[56] Many of the same database management and authorization issues that the FCC had to address with the TVBDs would have to be addressed if geo-location technology is implemented to protect federal radar systems.[57] NTIA, in conjunction with the DoD and other affected agencies,

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[54] The reciprocal of pulse repetition rate is the pulse repetition interval.

[55] The IEEE 802.11ac standard that is being developed does not include provisions for geo-location technology.

[56] As an interim procedure to protect Terminal Doppler Weather Radar (TDWR) systems from interference, the FCC requires U-NII devices within 35 kilometers of a TDWR location to be separated by at least 30 MHz from the TDWR operating frequency. *See* Federal Communications Commission Office of Engineering and Technology Laboratory Division Interim Plans to Approve UNII Devices Operating in the 5470 - 5725 MHz Band with Radar Detection and DFS Capabilities (Oct. 14, 2010) *available at* http://apps.fcc.gov/kdb/GetAttachment.html?id=dV24P2kaxB%2BkKzIPZxHxHg%3D%3D.

[57] The FCC designated multiple database administrators from the private sector to create and operate the Television Band Devices databases. Areas addressed by the FCC related to the database included: 1) the construction of the database(s), including its contents; 2) sharing of information among the databases; 3) the determination of available channels; and 4) required security provisions. FCC Public Notice, *Office of Engineering and Technology to Conduct Workshop for TV Bands Device Database Managers on March 10, 2011*, ET Docket No. 04-186, DA 11-404 (Mar. 1, 2011).

will examine in more detail whether geo-location spectrum-sharing technology could be used to mitigate the risks associated with signal sensing spectrum-sharing technologies.

Risk Element 2 - Changes in U-NII Device Deployment and Technical Parameters May Result in Harmful Interference

Representatives from industry provided information about U-NII device deployment and technical parameters that can be used in analyzing whether to introduce devices employing DFS sharing technology in the 5350-5470 MHz band. Appendix B provides NTIA's assessment of these U-NII device deployment and technical parameters. NTIA compared the information submitted by the group of industry representatives to the U-NII device deployment and technical parameters used in developing the existing U-NII regulations in the 5250-5350 MHz and 5470-5725 MHz bands. The assessment shows that U-NII device deployment parameters related to the total number of U-NII devices and the distribution of U-NII devices have changed from those used in the development of the existing regulations because U-NII technology is now incorporated in so many types of wireless devices.[58] Accordingly, these new deployment parameters need to be considered to determine whether the existing U-NII regulations are appropriate or what revisions are necessary to implement DFS sharing technology in the 5350-5470 MHz band. The density of U-NII devices is one of the key parameters in determining the amount of potential interference to the incumbent federal systems. It will be critical, working with industry, to establish a realistic U-NII device density before conducting the detailed technical analysis to accurately assess the impact of expanding access to the 5350-5470 MHz band.

The assessment of the U-NII device technical parameters indicates strong conformity with the industry inputs describing the distribution of U-NII device EIRP levels.[59] However, the industry recommendation for distribution of RF channel bandwidths and recent IEEE 802.11 amendments to U-NII device waveform modeling to cover all possible frame sizes differ from assumptions used in the development of the existing regulations.[60] These technical parameters require more detailed examination to determine if the existing U-NII regulations are appropriate or what revisions are necessary to introduce DFS sharing technology in the 5350-5470 MHz band.

Risk Element 3 - Existing U-NII Regulations May Not Adequately Protect Current and Future Radar Systems from Serious Degradation

The sharing scenarios for ground-based and shipborne radar systems and the methodology contained in NTIA Technical Memorandum 09-461 will serve as the basis for performing additional quantitative analytical studies assessing the potential impact of DFS-enabled U-NII devices to

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58 *Industry Input* at 4.

59 *Id.* at 5.

60 *Id.* at 4.

federal radar systems in the 5350-5470 MHz band.[61] NTIA, in conjunction with the DoD, will determine if the sharing scenarios and analysis methodology previously used adequately protect ground-based and shipborne radars operating in the 5350-5470 MHz band. The quantitative analysis results may show the need to modify the existing DFS regulations to adequately protect ground-based and shipborne radar systems operating in the 5350-5470 MHz band.

In developing the existing FCC U-NII regulations, the supporting analysis did not take into consideration airborne radar systems. Expanding the U-NII regulations to the 5350-5470 MHz band introduces a new airborne radar sharing scenario(s) that will need to be developed and evaluated. NTIA Technical Memorandum 09-461 described an airborne sharing scenario, but it was not used in the development of the detection thresholds specified in the existing FCC U-NII regulations.[62] NTIA, in conjunction with the DoD, will determine if the sharing scenarios and analysis methodology previously used in establishing the U-NII regulations addresses the identified risks for airborne radars operating in the 5350-5470 MHz band. The quantitative analysis results may show the need to modify the existing regulations to adequately protect airborne radar systems operating in the 5350-5470 MHz band.

Risk Element 4 - Changes to U-NII DFS Detection Parameters May Not Protect Current and Future Radar Systems from Serious Degradation

To improve range resolution and range accuracy, some radar systems in the 5350-5470 MHz band employ short (sub-microsecond) pulsewidths.[63] As shown in Appendix A, the smallest pulsewidth used in developing the existing U-NII regulations was 1 microsecond. The ability of signal sensing spectrum-sharing technologies to detect sub-microsecond pulses is not known at this time. It will be necessary to perform laboratory and field measurements to evaluate the capability to detect radar signals employing sub-microsecond pulses. NTIA, in conjunction with the DoD, will identify any changes to the existing signal parameters contained in Appendix A representing the radar systems operating in the 5350-5470 MHz band. To address this risk, the new waveforms will need to be used in laboratory testing of prototype devices. Testing with an operational radar system may be necessary to validate the effectiveness of any proposed changes to the U-NII regulations to address this risk. In addition, some recently fielded and in-development radar systems include low-power modes or are designed to avoid detection to meet their mission requirements. This may require a more detailed examination of cases where spectrum sensing spectrum-sharing technology may not protect radar systems (*e.g.*, radar systems designed to avoid detection).

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[61] NTIA Technical Memorandum TM-09-461, *Description of a Model to Compute the Aggregate Interference from Radio Local Area Networks Employing Dynamic Frequency Selection to Radars Operating in the 5 GHz Frequency Range* (May 2009), *available at* http://www.its.bldrdoc.gov/publications/2498.aspx.

[62] NTIA determined that the existing airborne radar operations could be accommodated in the 5350-5470 MHz portion of the band where there were no U-NII devices operating.

[63] A narrow pulsewidth also improves radar detection capabilities in cluttered environments.

Risk Element 5 - Existing U-NII Regulations May Introduce "Hidden Node" Interference that Seriously Degrades Performance

The current FCC regulations require only U-NII access point devices (also referred to as master devices) to perform the DFS channel availability check.[64] However, circumstances may arise where significant propagation loss differences occur between a radar system and the U-NII client devices operating within a network. In those cases, the assumption of a symmetrical propagation path between the radar system and the access point is not valid. The propagation path between the radar and the access point device may be obstructed, but the propagation path between the radar system and client devices ("hidden nodes") is unobstructed, potentially resulting in excessive interference to the radar system. The conditions under which the "hidden node" interference problem can occur will require examination to determine whether it is necessary to tailor the existing U-NII regulations (*e.g.*, incorporate DFS functionality in all U-NII devices).

Risk Element 6 - U-NII Devices Operating on an Adjacent Channel Can Cause Harmful Interference to Radar Systems

As part of the TDWR interference investigation, NTIA determined that, under certain conditions, U-NII devices operating on an adjacent channel could cause interference.[65] The U-NII devices considered in NTIA's investigation were located on buildings using high-gain directional antennas with clear line-of-sight to the TDWR. NTIA determined that the adjacent channel interference level was a function of frequency separation, distance separation, and antenna coupling.[66] The analysis and measurements performed to develop the existing U-NII DFS regulations did not consider the effects of adjacent channel interference. This analysis assumed that once a U-NII DFS device detected a radar signal it moved to a channel that was separated far enough in frequency to eliminate adjacent channel interference. Based on the TDWR interference investigation NTIA determined that some devices were not moving far enough away in frequency and their out-of-channel emissions were causing interference to TDWR. Given the anticipated increase in U-NII device density, adjacent channel interference to radar systems must be taken into account. The methodology in NTIA Technical Memorandum 09-461 will be expanded to include off-frequency interference from U-NII devices for a more detailed analysis. This more detailed analysis will consider various approaches to addressing the adjacent channel interference that can be included in the U-NII DFS regulations, such as establishing a minimum frequency separation or limits on out-of-channel emissions.

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[64] *See* 47 C.F.R. § 15.407(h)(2)(i)(A).

[65] NTIA Case Study Part III at 14.

[66] *Id.*

Risk Element 7 – Radar Receiver Interference Protection Criteria Used to Develop Existing U-NII DFS Regulations May Not Adequately Address Low-Level Interference Effects

In developing the existing U-NII DFS regulations NTIA established an interference threshold for the radar system receivers based on an interference-to-noise ratio of -6 decibel (dB). NTIA determined harmful interference to radar systems can occur even when there are low levels of interference.[67] Loss of targets at low interference levels is sometimes difficult to assess because there is no overt indication to the operator or even sophisticated radar software that the target losses are occurring. To address these low-level interference effects, it may be necessary to use more stringent interference protection criteria for radar receivers. As part of the quantitative study, it will be necessary to evaluate the interference protection criteria used in the development of the current DFS regulations and revise the interference protection criteria as necessary to address low-level interference effects.

Risk Element 8 – Channel Response Time Requirements in the Current DFS Regulations May Not be Adequate to Protect All Radar System Operational Scenarios

The U-NII DFS certification tests do not include a requirement for how quickly a device must detect a radar system. The channel move time requirement only specifies that, after a radar system is detected, all U-NII device transmissions are required to cease operation on the radar frequency channel with a move time of 10 seconds. Transmissions for normal traffic during this period are limited to a maximum of 200 milliseconds after detection of the radar signal. The feasibility of establishing specifications for U-NII channel response time, which includes the U-NII device listening frequency and dwell time, must be investigated. As part of the quantitative study the different radar system operational scenarios will need to be evaluated to determine if it is necessary to establish a requirement for how quickly (from the first pulse above the detection threshold) a U-NII device must detect the radar system. The projection of the expected stream of pulses over the detection threshold also needs to be evaluated in order to specify the frequency and dwell time requirements of the U-NII device detection window. The methodology in NTIA Technical Memorandum 09-461 needs to be modified to evaluate listening frequency and dwell time requirements and to support the revisions in Recommendation ITU-R M.1652 for the IEEE 802.11ac data transmissions. If new listening frequency and dwell time requirements are deemed necessary, they would need to be incorporated into the U-NII DFS certification test procedures.

[67] *Technical Report TR-06-444* at 137.

DESCRIPTION OF RISKS TO AIRBORNE SYSTEM OPERATIONS IN THE 5350-5470 MHZ BAND

Risk Element 1 - Current U-NII Regulations Were Not Developed to Detect Airborne Signals

Signals from ground-based and airborne transmitters were not considered in the development of the existing U-NII regulations because these system operations were not part of the previous studies for U-NII devices. To evaluate whether the existing U-NII device regulations can be used to detect airborne signals, representative technical parameters for ground-based and airborne transmitters and receivers will have to be developed, as well as sharing scenarios associated with UAS operations. The methodology documented in NTIA Technical Memorandum 09-461 can serve as the basis for performing the analytical studies assessing the potential impact of DFS-enabled U-NII devices to federal airborne systems. The analysis of the different sharing scenarios will show whether DFS can be implemented to address the identified risk.

Risk Element 2 - U-NII Signal Detection Technologies May Not Be Capable of Detecting Airborne Signals Resulting in Serious Performance Degradation

The following paragraphs evaluate the impact on different spectrum-sharing technologies related to the risk associated with detecting digital airborne signals.

Energy Detection. Airborne signals employ digital formats with complex modulation schemes that have different spectral characteristics than the pulsed signals transmitted by radar systems used in the development of the existing U-NII device regulations. Since threshold detection does not require knowledge of the environmental signal characteristics, it could be an effective spectrum-sharing technology for U-NII devices operating in the 5350-5470 MHz band. NTIA, in conjunction with the DoD and wireless industry representatives, will attempt to define parameters of airborne signals so that this spectrum-sharing technology can address the identified risk.

Matched Filter Detection. Threshold detection, in conjunction with matched filter technology, is currently being used to improve the detection capabilities for sharing between U-NII devices employing digital modulation formats. The signal parameters associated with the U-NII device data transmissions are well defined, thereby enhancing matched filter performance. NTIA, in conjunction with the DoD and industry representatives, will attempt to define parameters of airborne signals in such a way as to use matched filter technology to improve detection capabilities of U-NII devices to address the identified risk.

Signal Detection. Signal detection technology, employing a combination of threshold detection and signal parameter pattern recognition as currently used by U-NII DFS-enabled devices operating in the 5250-5350 MHz and 5470-5725 MHz bands, is designed to detect pulsed radar signals (parameters shown in Appendix A). Digital UAS signals' spectral characteristics differ from pulsed radar signals' spectral characteristics currently detected by U-NII DFS enabled devices. NTIA, in conjunction with DoD and industry representatives, will determine whether they can use or adapt existing signal detection techniques for sharing among U-NII devices to detect ground-based and airborne UAS signals to address the identified risk.

Geo-Location. The FCC regulations for U-NII devices and the IEEE 802.11ac standard do not address geo-location spectrum-sharing technology. To implement geo-location technology, a database could be developed of UAS ground-based transmitter and receiver locations around which to establish protection distances and/or frequency restrictions. It may be possible to use frequency relationships between the ground-based UAS transmitters to protect airborne UAS receivers.[68] Many of the same database management and authorization issues that the FCC had to address with TVBDs would have to be addressed if geo-location technology is implemented to protect federal UAS systems. NTIA, in conjunction with DoD and the industry representatives, will examine in more detail whether geo-location spectrum-sharing technology could be used to mitigate the risks associated with ability of signal sensing spectrum-sharing technologies to protect UAS operations.

Risk Element 3 - Current U-NII Regulations Were Not Developed to Protect Systems Where the Transmitter and Receiver are Not Co-Located

The existing U-NII regulations were developed specifically to protect radar receivers from interference where the transmitter and receiver are co-located. UAS employ ground and airborne transmitters and receivers located in different locations. Full duplex systems with the uplink and downlink on different frequencies can introduce a different "hidden node" problem.[69] A "hidden node" could occur when a U-NII device is signal sensing on a RF channel and the path between the U-NII device and a UAS ground transmitter is blocked by terrain. The U-NII device is not able to detect the signal from the UAS ground transmitter and would identify that RF channel as unoccupied and available for use. However, there could be an airborne UAS receiver operating on that RF channel in view of U-NII devices, resulting in potential interference to the UAS airborne receiver as shown in Figure 4-1.

[68] This solution may not address potential interference to mobile UAS receivers with nationwide frequency assignments, because to date the database method has been used for non-mobile operations, as the data is fixed and known, whereas data for mobile receivers is not fixed and known.

[69] *See* Facilitating Opportunities for Flexible, Efficient, and Reliable Spectrum Use Employing Cognitive Radio Technologies, *Notice of Proposed Rulemaking and Order*, ET Docket No. 03-108, 18 F.C.C. Rcd. 26859, 26868 (2003), *available at* http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-03-322A1.pdf.

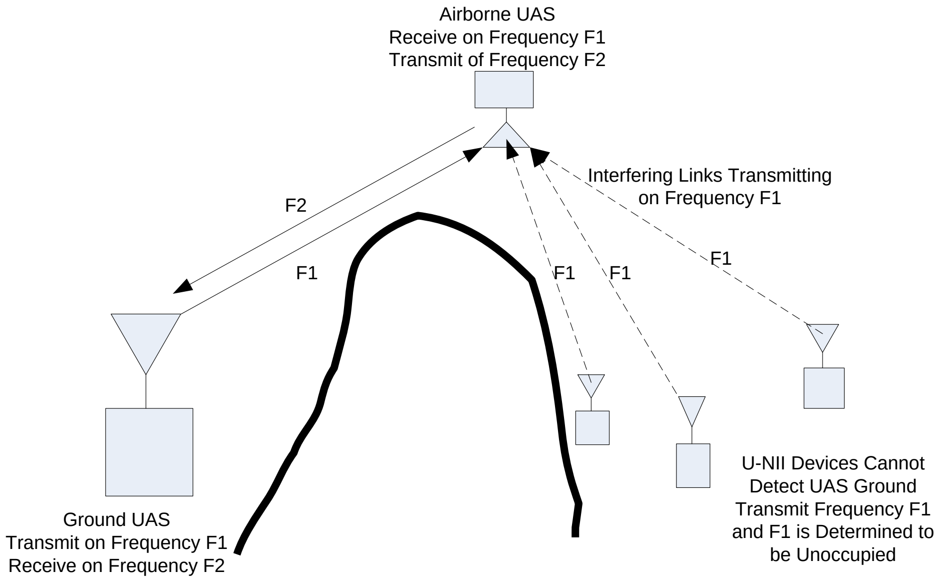

Figure 4-1. Example of "Hidden Node" Problem

Radar transmitters and receivers operate on the same frequency, whereas UAS transmitters and receivers operate on different frequencies. It may be possible to use frequency relationships between the UAS transmitters and receivers to address the "hidden node" problem. If the U-NII devices are able to detect the UAS airborne transmit frequency (F2 in Figure 4-1), and there is a known relationship between the transmitter and receiver frequencies, the U-NII devices can avoid transmitting on the UAS receive frequency, thereby eliminating the interference to the UAS receiver. If the UAS transmitter/receiver operating frequency information does not change, it could be provided in a look-up table or specified on a geographic basis, using a database in conjunction with geo-location technology. NTIA will work with DoD to determine whether the UAS transmitter and receiver frequency information can be made available. NTIA will also work with industry representatives to determine if they can implement this approach or have alternative solutions, such as cooperative sensing or beacons, to address the identified risk associated with the "hidden node" problem.

Risk Element 4 - Changes to DFS Detection Parameters May Not Protect UAS Operations from Serious Performance Degradation

The ability of DFS signal sensing spectrum-sharing technologies to detect digital UAS signals is not known at this time. It will be necessary to perform laboratory and field measurements to evaluate the capability of DFS to detect UAS signals. NTIA, in conjunction with the DoD, will develop representative test waveforms for laboratory measurements to verify DFS detection capabilities. To address this risk, laboratory testing of prototype devices will require new waveforms to represent UAS signals. Depending on the results of the laboratory measurements, testing with an operational UAS system may be necessary to validate the effectiveness of any proposed changes to the U-NII regulations to address this risk.

DESCRIPTION OF RISKS TO SPACEBORNE SAR OPERATIONS IN THE 5350-5470 MHZ BAND

Risk Element 1 - Existing U-NII Regulations Were Not Developed to Protect Spaceborne SAR Receivers

Spaceborne SAR transmitters were not considered in the development of the existing FCC U-NII regulations. In preparation for the 2003 World Radiocommunication Conference (WRC-03), Canada performed technical studies examining sharing between SAR receivers and radio local area network (RLAN) devices.[70] The studies performed by Canada were based on specific technical and deployment assumptions for the RLAN devices. NTIA will use updated deployment and technical information for U-NII devices in quantitative analytical studies to determine the potential interference impact to SAR receivers to address the identified risk.

The studies in Recommendation ITU-R RS.1632, indicated that sharing was possible when certain restrictions were placed on the RLAN devices, including: indoor deployment, maximum EIRP of 23 dBm, TPC, and a uniform spreading of the channel loading across the band.[71] An EIRP elevation angle mask as shown in Table 4-2 is a possible mitigation technique to improve compatibility between RLAN devices and SAR receivers.[72]

Table 4-2. Internationally Adopted RLAN EIRP Mask

EIRP (dBW/MHz)	θ (Angle in degrees above the local horizontal plane of the Earth)
-13	$0° \leq \theta < 8°$
-13 - 0.716 (θ - 8)	$8° \leq \theta < 40°$
-35.9 - 1.22 (θ - 40)	$40° \leq \theta \leq 45°$
-42	$45° < \theta$
Devices operating above an EIRP of 23 dBm must comply with this EIRP elevation angle mask.	

An analysis assessing potential compatibility will need to examine limitations on U-NII device deployment and technical parameters as well as other mitigation techniques to determine if they can be implemented to adequately mitigate the potential interference to SAR receivers and address the identified risk.

70 Recommendation ITU-R RS.1632, *Sharing in the band 5250-5350 MHz between the Earth exploration-satellite service (active) and wireless access systems (including radio local area networks) in the mobile service* (2003).

71 *Id.* at 28.

72 International Telecommunication Union Final Acts World Radiocommunication Conference 2003, *Resolution 229 Use of the bands 5150-5250 MHz, 5250-5350 MHz, and 5470-5725 MHz by the mobile service for the implementation of wireless access systems including radio local area networks.*

ADDITIONAL SAFEGUARDS TO FACILITATE SPECTRUM-SHARING ARRANGEMENTS

The current FCC regulations for 5250-5350 MHz and 5470-5725 MHz allow U-NII DFS devices to be used indoors and outdoors. This analysis, performed as part of the quantitative study, makes a distinction between U-NII devices that are deployed outdoors for mobile applications using lower EIRP levels and omni-directional antennas, and U-NII devices deployed on buildings or towers used for point-to-point communication applications employing higher EIRP levels and high gain directional antennas. Based on the industry projections, NTIA will perform analysis limiting the U-NII devices operating in the 5350-5470 MHz band to a maximum EIRP of 20 dBm. Since the current FCC U-NII regulations only require TPC to be employed for devices operating with an EIRP of greater than 27 dBm, NTIA will assume as part of the quantitative analysis that TPC will not be required for U-NII devices operating in the 5350-5470 MHz band.[73] U-NII devices used for point-to-point applications will not be considered because without DFS these devices are incompatible with radar systems (*e.g.*, TDWR interference from point-to-point U-NII device applications). It is difficult to enforce rules that require U-NII devices to operate indoors; however, placing limitations on the EIRP reduces the operational range of the U-NII devices used for outdoor applications.[74]

Upon developing agreed upon sharing scenarios identified for radar, UAS, and SAR systems operating in the 5350-5470 MHz band, NTIA will perform a quantitative analysis to determine if these limitations on U-NII devices improve sharing with federal systems.

[73] TPC is a feature that adjusts a transmitter's output power based on the signal level present at the receiver. As the signal level at the receiver rises or falls, the transmit power will decrease or increase as needed. Therefore, TPC will cause the U-NII device transmitter to operate at less than the maximum power when lower signal levels can provide acceptable service.

[74] U-NII devices operating in the 5150-5250 MHz band are restricted to indoor operation to reduce any potential for harmful interference to co-channel mobile-satellite service operations. *See* 47 C.F.R. § 15.407(e). The FCC has established requirements for the indoor use of ultrawideband devices including the necessity to operate with a fixed indoor infrastructure (*e.g.*, a transmitter that must be connected to the AC power line) and a prohibition on any fixed outdoor infrastructure. *See* 47 C.F.R. § 15.517.

SECTION 5. EVALUATION OF RISKS TO FEDERAL SYSTEMS OPERATING IN THE 5850-5925 MHZ BAND

INTRODUCTION

This section describes the evaluation of the risks to federal systems and the possible mitigation strategies associated with allowing U-NII devices to operate in the 5850-5925 MHz band.

OVERVIEW OF SYSTEMS OPERATING IN THE 5850-5925 MHZ BAND

In the United States, the 5650-5925 MHz band is allocated for federal radiolocation service, restricted to military services, on a primary basis.[75] The 5850-5925 MHz band is also allocated to non-federal fixed-satellite (Earth-to-space) and mobile services on a primary basis. However, the non-federal fixed-satellite service allocation is limited to international inter-continental systems and is subject to case-by-case electromagnetic compatibility analysis.[76] The non-federal mobile service allocation is limited to Dedicated Short Range Communications Service (DSRCS) systems operating in the Intelligent Transportation System radio service.[77] An overview of the federal systems operating in the 5850-5925 MHz band is provided below. A more detailed description of the DoD systems operating in this band is provided in Appendix C.

Dedicated Short Range Communications Service Systems

The Department of Transportation (DOT) has advocated for the allocation of spectrum for DSRCS systems to facilitate incorporating technology and advanced electronics into the nation's surface transportation infrastructure.[78] Although licensed by the FCC, DSRCS systems will enhance safety on the nation's highways. Analyses by DOT's National Highway Traffic Safety Administration (NHTSA) show DSRCS-based connected vehicle technology could potentially address approximately 80 percent of the crash scenarios involving non-impaired drivers. Specifically, NHTSA research shows that this technology could help prevent the majority of types of crashes that typically occur in the real world, such as crashes at intersections or while changing

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[75] *See* 47 C.F.R. § 2.106, Federal Government (G) footnote G2.

[76] *See id.* at United States (US) footnote US245. There are also secondary allocations for the amateur service in the 5650-5925 MHz band and the amateur satellite service in the 5830-5850 MHz portion of the band.

[77] *See id.* at Non-Federal Government footnote NG160.

[78] *See* Notice to the FCC of *Ex Parte* Meeting – WT Docket No. 1-90 and ET Docket No. 98-95, Dedicated Short-Range Communications of Intelligent Transportation Services (U.S. Department of Transportation, July 30, 2012). *See also* Petition of the Intelligent Transportation Society of America for Amendment of the Commission's Rules to Add Intelligent Transportation Services (ITS) as a New Mobile Service with Co-Primary Status in the 5850-5925 MHz Band (May 19, 1997). The Intelligent Transportation Society of America served as a Utilized Federal Advisory Committee to the Department of Transportation at the time of the 1997 filing, but no longer serves that function.

lanes.[79] For the purpose of this study, NTIA treats DSRCS systems like a federal system in assessing the feasibility of allowing U-NII devices to operate in the 5850-5925 MHz band.

Intelligent Transportation System stations operating DSRCS are authorized to operate in the 5850-5925 MHz band.[80] DSRCS systems are used to transfer data over short distances between roadside and mobile units, between mobile units, and between mobile and portable units to perform operations related to the improvement of traffic flow, traffic safety, and other intelligent transportation service applications in a variety of environments.[81] DSRCS operations involve two types of devices: a Road Side Unit (RSU) and an On-Board Unit (OBU).[82]

The IEEE 802.11p standard is used for medium access control and physical layer application for the wireless connectivity using DSRCS.[83] The American Society for Testing and Materials (ASTM) E2213 standard specifies the transmitter and receiver specifications for DSRCS RSU and OBU equipment as well as a channel plan.[84] While the ASTM was initially intended to serve as the standard for DSRC operations, much of this work was moved to IEEE 802.11 to gain broader acceptance of the standard within the manufacturing industry. As 802.11p developed, many corrections and updates were implemented. Appendix D provides a detailed description of the DSRCS system.

Radar Systems

The radars that operate in the 5850-5925 MHz band are primarily military systems that can tune across the entire 5400-5900 MHz frequency range. Radars operating in this band segment can be either mobile or transportable and are used for surveillance and test range instrumentation. Test range instrumentation radars provide highly accurate position data on space launch vehicles and aeronautical vehicles undergoing developmental and operational testing. FCC rules require that

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79 *See* NHTSA, *Fact Sheet: Improving Safety and Mobility Through Connected Vehicle Technology - U.S. Department of Transportation Safety Pilot*, *available at* http://www.its.dot.gov/safety_pilot/pdf/safetypilot_nhtsa_factsheet.pdf.

80 *See* Amendment of the Commission's Rules Regarding Dedicated Short-Range Communications Services in the 5.850-5.925 GHz (5.9 GHz Band), *Report and Order*, WT Docket 01-90, FCC 03-324 (2003), *available at* http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-03-324A1.pdf; *Memorandum Opinion and Order*, WT Docket No. 01-90, FCC 06-110 (2006), *available at* http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-06-110A1.pdf.

81 DSRCS systems support both public safety and private operations in roadside-to-vehicle and vehicle-to-vehicle communication environments.

82 RSUs operate at fixed locations and are authorized under Part 90 of the FCC rules. *See* 47 C.F.R. §90.371. OBUs are mobile devices located in an automobile and authorized under Part 95 of the FCC rules. *See* 47 C.F.R. §95.1501.

83 IEEE 802.11p, *IEEE Standard for Information technology – Telecommunications and information exchange between systems – Local and metropolitan area networks – Specific requirements Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications Amendment 6: Wireless Access in Vehicular Environments* (2010).

84 American Society for Testing and Materials, ASTM E2213-03, *Standard Specification for Telecommunications and Information Exchange Between Roadside and Vehicle Systems – 5 GHz Band Dedicated Short Range Communications (DSRC) Medium Access Control (MAC) and Physical Layer (PHY) Specifications* (Reapproved 2010).

DSRCS RSU stations operating within 75 kilometers of 59 radar installations be coordinated through NTIA.[85]

In addition to the radar systems used by the DoD, several other agencies operate radar systems in the band. NASA uses this band for test and launch range instrumentation radars to track rockets, missiles, satellites, launched vehicles, and other targets. These radars provide the prime coverage for range safety. Range instrumentation radar transponders also operate in the band to enhance radar tracking of low cross section aircraft and missiles and systems under test. The National Oceanic and Atmospheric Administration operates radar systems in the band that are used on "Hurricane Hunter" aircraft. The Department of Energy operates radar systems and their associated transponders in the band located at four test ranges throughout the United States.

Commercial Satellite Communication Systems

The military agencies lease capacity on commercial satellite systems to satisfy their communication requirements. The satellite terminals transmit an uplink signal in the 5850-6425 MHz band and receive a downlink signal in the 3700-4200 MHz band. As a result of this configuration, the satellite terminal receiver will not be impacted by U-NII device operations in the 5850-5925 MHz band. However, there is potential interference problem to the receiver on-board the satellite. Since the military agencies only lease the service as customers, it is anticipated that the impact to the satellite receiver will be addressed by the FCC working with the commercial satellite service providers and will not be considered as part of this study.

IDENTIFICATION OF RISKS TO SYSTEMS OPERATING IN THE 5850-5925 MHZ BAND

The risks identified in this study reflect the potential for interference to federal systems if the FCC allows U-NII devices to operate in the 5850-5925 MHz band. This interference could result from the technical and operational characteristics of federal systems and/or the technical and deployment parameters of the U-NII devices. Where feasible, the federal agencies conducted preliminary analyses using the existing U-NII regulations and estimated deployment parameters to quantify the interference risks. Table 5-1 provides an overview of the risk elements and suggested mitigation strategies for each category of system associated with allowing U-NII device operation in the 5850-5925 MHz band.

[85] *See* 47 C.F.R. § 90.371(b).

Table 5-1. Overview of Risk Elements and Suggested Mitigation Strategies Associated with the 5850-5925 MHz Band

System Category	Description of Risk Element	Suggested Mitigation Strategy
Radar	Risk Element 1 - Changes in radar signal parameters may impact U-NII device detection of radar systems.	- Review radar signal parameters used in the development of existing regulations and assess whether U-NII device spectrum sharing technologies can be used to protect current and future radar systems.
	Risk Element 2 - Changes in U-NII device deployment and technical parameters may result in harmful interference.	- Update U-NII device deployment and technical parameters to be used in the quantitative analysis.
	Risk Element 3 - Existing U-NII regulations may not adequately protect current and future radar systems from serious degradation.	- Identify new sharing scenarios for radar systems. - Perform quantitative analysis to evaluate current DFS regulations.
	Risk Element 4 - Changes to existing U-NII DFS detection parameters may not protect current and future radar systems from serious degradation.	- Develop representative test signals for laboratory measurements to verify DFS detection capabilities. - Perform laboratory measurements using prototype devices and simulated radar signals. - Perform field measurements using actual radar signals to verify laboratory measurements. - Modify existing DFS regulations based on the results of quantitative analysis and measurements.
	Risk Element 5 – Existing U-NII regulations may introduce “hidden node” interference.	- Examine the conditions under which “hidden node” interference exists. - Modify U-NII device regulations as needed to resolve “hidden node” interference.
	Risk Element 6 – U-NII devices operating on an adjacent channel may cause harmful interference to radar systems.	- Perform quantitative analysis to assess the impacts of adjacent channel interference. - Perform measurements to evaluate different options for addressing adjacent channel interference. - Modify existing U-NII device regulations based on the results of quantitative analysis and measurements.
	Risk Element 7 – Radar receiver interference protection criteria used to develop existing U-NII DFS regulations may not address low-level interference effects.	- Evaluate the interference protection criteria used in the development of the current DFS regulations to determine if they adequately protect systems from interference effects. - If necessary, revise the interference protection criteria to address low-level interference effects.
	Risk Element 8 – Channel response time requirements in the current DFS regulations may not be adequate to protect all radar system operational scenarios.	- Perform analysis to determine if it is necessary to add a channel response time to the DFS regulations to protect radar systems operating in different scenarios. - Modify the existing U-NII DFS device certification test procedures based on the results of the analysis.

Table 5-1. Overview of Risk Elements and Suggested Mitigation Strategies Associated with the 5850-5925 MHz Band (Continued)

System Category	Description of Risk Element	Suggested Mitigation Strategy
DSRCS	Risk Element 1 - Existing U-NII DFS regulations were not developed to detect DSRCS signals.	- Develop representative technical parameters and sharing scenarios to examine impact to DSRCS RSU and OBU stations including the mobile nature of RSU devices. - Perform analysis to evaluate whether current DFS regulations protect DSRCS receivers.
	Risk Element 2 - U-NII signal detection technologies may not be capable of detecting DSRCS signals.	- Determine if current signal detection techniques for sharing among U-NII devices can be used or adapted to detect DSRCS RSU and OBU signals.
	Risk Element 3 - Current U-NII regulations were not developed to protect non-co-located transmitters and receivers.	- Examine the conditions under which a "hidden node" problem exists. - Identify any possible sharing approaches for more detailed analysis.
	Risk Element 4 - Changes to U-NII DFS detection parameters may not protect DSRCS systems from serious performance degradation.	- Develop representative test signals for laboratory measurements to verify DFS detection capabilities. - Perform laboratory measurements using prototype devices and simulated DSRCS signals. - Perform field measurements using actual DSRCS signals to verify laboratory measurements. - Modify existing DFS regulations based results of quantitative analysis and measurements.

DESCRIPTION OF RISKS TO RADAR OPERATIONS IN THE 5850-5925 MHZ BAND

Risk Element 1 - Changes in Radar Signal Parameters May Impact U-NII Device Detection of Radar Systems

The following paragraphs evaluate the impact on different spectrum-sharing technologies related to the risk element associated with changing the signal parameters of federal radar systems.

Energy Detection. As discussed in the evaluation of the 5350-5470 MHz band, threshold detection does not require knowledge of the radar signal characteristics, and will minimize the risk associated with changes in the signal parameters that can impact the detection of ground-based radar systems operating in the 5850-5925 MHz band. However, recently fielded and in-development radar systems that include low-power modes or are designed to avoid detection to meet their mission requirements may present challenges for this spectrum sharing technology.

Matched Filter Detection. Matched filter detection technology, as discussed in the evaluation of the 5350-5470 MHz band, requires *a priori* knowledge of the characteristics of the radar signals to be effective. This spectrum-sharing technology will not address the risk associated with changing radar signal parameters that can impact detection of the ground-based radar systems operating in the 5850-5925 MHz band.

Signal Detection. Signal sensing is performed between data transmissions. Signal detection could be impacted by the wider bandwidth signals and higher data rates envisioned under the IEEE 802.11ac standard. NTIA must analyze in more detail the impact that this reduction in sensing time will have on detecting the ground-based radar systems operating in the 5850-5925 MHz band to determine if this spectrum-sharing technology addresses the identified risk. In addition, recently fielded and in-development radar systems that include low-power modes or are designed to avoid detection to meet their mission requirements may present challenges for this spectrum sharing technology.

Geo-Location. The FCC rules specify the latitudes and longitudes of the 59 ground-based radar installations that must be protected from DSRCS RSU stations.[86] A coordination distance of 75 kilometers is specified around each radar installation.[87] Since the transmitter and receiver for a radar system are at the same location, geo-location technology should be a very effective spectrum-sharing technology. To implement geo-location technology, a database of the radar locations around which a coordination distance is established would have to be developed. NTIA will perform further detailed technical analysis to determine if the 75 kilometers specified in the FCC Rules to protect radars from DSRCS RSU is the appropriate distance to protect radars operating in the 5850-5925 MHz band from U-NII devices. NTIA, in conjunction with the DoD, will examine in more detail whether geo-location spectrum-sharing technology could mitigate the risks associated with signal sensing spectrum-sharing technologies in the 5850-5925 MHz band.

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[86] *See* 47 C.F.R. § 90.371(b).

[87] *Id.*

Risk Element 2 - Changes in U-NII Device Deployment and Technical Parameters May Result in Harmful Interference

Industry representatives from companies that are interested in expanding unlicensed use of the 5 GHz band in support of IEEE 802.11ac provided information about U-NII device deployment and technical parameters that can be used in analyzing whether to introduce DFS sharing technology in the 5850-5925 MHz band. An assessment of these U-NII device deployment and technical parameters is provided in Appendix B. The assessment compared the information submitted by industry for the U-NII device deployment and technical parameters to those used in developing the existing U-NII regulations in the 5250-5350 MHz and 5470-5725 MHz bands. Based on this assessment, the total number of U-NII devices and the distribution of U-NII devices differ from those used in the development of the existing regulations.[88] NTIA needs to examine these differences in more detail to determine if the existing U-NII regulations are appropriate and, if not, what revisions are necessary to introduce DFS sharing technology in the 5850-5925 MHz band. The density of U-NII devices is one of the key parameters in determining the amount of potential interference to the incumbent federal systems. Establishing a realistic U-NII device density before conducting the detailed technical analysis is critical to accurately assessing the impact of expanding access to the 5850-5925 MHz band to U-NII devices.

The assessment of the U-NII device technical parameters indicated strong conformity with the wireless industry input describing the distribution of U-NII device EIRP levels.[89] However, the recommended distribution of RF channel bandwidths, and revisions to how the U-NII device waveforms are modeled to cover all possible frame sizes that are allowed by recent IEEE 802.11 amendments differ from those used in the development of the existing regulations.[90] NTIA needs to examine these technical parameters in more detail to determine if the existing U-NII regulations are appropriate or what revisions are necessary to implement DFS sharing technology in the 5850-5925 MHz band.

Risk Element 3 - Existing U-NII Regulations May Not Adequately Protect Current and Future Radar Systems from Serious Degradation

The sharing scenarios for ground-based radar systems and methodology documented in NTIA Technical Memorandum 09-461 serves as the basis for performing the quantitative analytical studies assessing the potential impact of DFS enabled U-NII devices to federal radar systems in the 5850-5925 MHz band.[91] NTIA, in conjunction with the DoD, will determine if the sharing scenarios and analysis methodology previously used in establishing the FCC U-NII regulations

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[88] *Industry Input* at 4.

[89] *Id.* at 5.

[90] *Id.* at 4.

[91] The methodology in NTIA Technical Memorandum TM-09-461 will need to be expanded to address off-frequency interference from U-NII devices.

addresses the identified risks for the ground-based radar systems operating in the 5850-5925 MHz band for the more detailed quantitative technical analysis.

Risk Element 4 - Changes to Existing U-NII DFS Detection Parameters May Not Protect Current and Future Radar Systems from Serious Degradation

NTIA Report 99-359 provides representative signal parameters (*e.g.*, pulsewidth, pulse repetition interval) for radar systems operating in the 5850-5925 MHz band.[92] As indicated by these signal parameters, some radars operating in the band employ sub-microsecond pulsewidths. As shown in Appendix A, the smallest pulsewidth used in the development of the existing U-NII regulations was 1 microsecond. The narrow pulsewidths in conjunction with the higher data rates associated with the 802.11ac standard could have an impact on the detection of pulsed radar signals. The ability of signal sensing spectrum-sharing technologies to detect sub-microsecond pulses is not known at this time. It will be necessary to perform laboratory and field measurements to evaluate the capability of U-NII devices to detect radar signals employing sub-microsecond pulses. NTIA, in conjunction with the DoD, will identify any changes to the existing signal parameters contained in Appendix A representing the radar systems operating in the 5850-5925 MHz band. To address this risk, the new waveforms will have to be used in laboratory testing of prototype devices. Depending on the results of the laboratory measurements, testing using an operational radar system may be necessary to validate the effectiveness of any proposed changes to the U-NII regulations to address this risk. In addition, some recently-fielded and in-development radar systems include low-power modes or were designed to avoid detection to meet their mission requirements. This may require a more detailed examination of cases where spectrum sensing spectrum-sharing technology may not protect radar systems (*e.g.,* radar systems designed to avoid detection).

Risk Element 5 - Existing U-NII Regulations May Introduce "Hidden Node" Interference

The FCC currently requires only access point devices to employ DFS functionality. However, circumstances may arise where significant propagation loss differences occur between a radar system and the client devices operating within a network. In these cases, the assumption of a symmetrical propagation path between the radar system and the access point is not valid. In these instances, the propagation path between the radar and the access point device may be obstructed, but the propagation path between the radar system and client devices ("hidden nodes") is unobstructed, potentially resulting in excessive interference to the radar system. NTIA will need to examine the conditions under which the "hidden node" interference problem can occur to determine whether it is necessary to modify the existing U-NII regulations (*e.g*., incorporate DFS functionality in all U-NII devices).

[92] NTIA Technical Report TR-99-359, *Electromagnetic Compatibility Testing of a Dedicated Short-Range Communication (DSRC) System that Conforms to the Japanese Standard* (Nov. 1998), *available at* http://www.its.bldrdoc.gov/publications/2390.aspx.

Risk Element 6 - U-NII Devices Operating on an Adjacent Channel Can Cause Harmful Interference to Radar Systems

As part of the TDWR interference investigation, NTIA determined that, under certain conditions, U-NII devices operating on an adjacent channel could cause interference.[93] The U-NII devices considered in NTIA's investigation were located on buildings using high-gain directional antennas with clear line-of-sight to the TDWR. NTIA determined that the adjacent channel interference level was a function of frequency separation, distance separation, and antenna coupling.[94] The analysis was performed to develop the existing U-NII DFS regulations did not consider the effects of adjacent channel interference. This analysis assumed that once a U-NII DFS device detected a radar signal it moved to a channel that was separated far enough in frequency to eliminate adjacent channel interference. Based on the TDWR interference investigation NTIA determined that some devices were not moving far enough away in frequency and their out-of-channel emissions were causing interference to TDWR. Given the anticipated increase in U-NII device density adjacent channel interference to radar systems must be taken into account. The methodology in NTIA Technical Memorandum 09-461 will be expanded to include off-frequency interference from U-NII devices. The analysis will consider various approaches to addressing the adjacent channel interference that can be included in the U-NII DFS regulations such as establishing a minimum frequency separation or limits on out-of-channel emissions.

Risk Element 7 – Radar Receiver Interference Protection Criteria Used to Develop Existing U-NII DFS Regulations May Not Adequately Address Low-Level Interference Effects

In developing the existing U-NII DFS regulations NTIA established an interference threshold for the radar system receivers based on an interference-to-noise ratio of -6 dB. NTIA performed a study that determined harmful interference to radar systems can occur when there are low levels of interference.[95] NTIA concluded that the loss of targets at low interference levels is sometimes difficult to assess because there is no overt indication to the operator or even sophisticated radar software that the target losses are occurring. To address these low-level interference effects, it may be necessary to use more stringent interference protection criteria for the radar receivers. As part of the quantitative study, it will be necessary to evaluate the interference protection criteria used in the development of the current DFS regulations and revise the interference protection criteria as necessary to address low-level interference effects.

Risk Element 8 – Channel Response Time Requirements in the Current DFS Regulations May Not be Adequate to Protect All Radar System Operational Scenarios

U-NII DFS certification tests do not include a requirement on how quickly a device must detect a radar system. The channel move time requirement only specifies that after a radar system

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[93] NTIA Case Study Part III at 14.

[94] *Id.*

[95] Technical Report TR-06-444.

is detected all U-NII device transmissions are required to cease operation on the radar frequency channel with a move time of 10 seconds. Transmissions for normal traffic during this period are limited to a maximum of 200 milliseconds after detection of the radar signal. The feasibility of establishing specifications for U-NII channel response time, which includes the U-NII device listening frequency and dwell time, must be investigated. As part of the quantitative study, NTIA will evaluate the different radar system operational scenarios to determine if it is necessary to establish a requirement for how quickly (from the first pulse above the detection threshold) a U-NII device must detect the radar system. The projection of the expected stream of pulses over the detection threshold also needs to be evaluated in order to specify the frequency and dwell time requirements of the U-NII device detection window. The methodology in NTIA Technical Memorandum 09-461 needs to be modified to evaluate listening frequency and dwell time requirements and to support the revisions in Recommendation ITU-R M.1652 for the IEEE 802.11ac data transmissions. If new listening frequency and dwell time requirements are deemed necessary, they would need to be incorporated into the U-NII DFS certification test procedures.

DESCRIPTION OF RISKS TO DSRCS OPERATIONS IN THE 5850-5925 MHZ BAND

Risk Element 1 - Current U-NII Regulations Were Not Developed to Detect Digital DSRCS Signals

Signals from RSU (fixed) and OBU (mobile) DSRCS transmitters were not considered in the development of the existing U-NII regulations because there is no DSRCS in the bands governed by the existing U-NII regulations. To evaluate whether the existing U-NII device regulations can be used to detect signals from RSU and OBU stations, representative technical parameters will have to be developed with input from DOT and the intelligent transportation community. The sharing scenarios associated with DSRCS operations will also have to be developed, in collaboration with DOT, the transportation community and the wireless industry. The methodology documented in NTIA Technical Memorandum 09-461 would serve as the basis for performing the analytical studies assessing the potential impact of DFS enabled U-NII devices to DSRCS systems. An analysis of the different sharing scenarios could determine if DFS can be implemented to address the identified risk.

Risk Element 2 - U-NII Signal Detection Technologies May Not Be Capable of Detecting DSRCS Signals

The following paragraphs evaluate the impact on different spectrum-sharing technologies related to the risk associated with detecting digital DSRCS signals.

Energy Detection. DSCRS signals will employ digital orthogonal frequency-division multiplexing (OFDM), which has different spectral characteristics than the pulsed signals transmitted by radar systems used in the development of the existing U-NII device regulations. Since threshold detection does not require knowledge of the environmental signal characteristics, it could be an effective spectrum-sharing technology for U-NII devices operating in the 5850-5925 MHz band. NTIA, in conjunction with DOT and wireless and transportation industry representatives, will determine if the parameters of DSRCS signals can be defined in such a way as to use this spectrum-sharing technology to address the identified risk.

Matched Filter Detection. Threshold detection, in conjunction with matched filter technology, is currently being used to improve the detection capabilities for sharing between U-NII devices employing digital modulation formats. The well-defined signal parameters associated with the U-NII device data transmissions enhance matched filter performance. NTIA, in conjunction with DOT and transportation and wireless industry representatives, will determine if they can define parameters of DSRCS signals in such a way as to use matched filter technology to improve detection capabilities of U-NII devices to address the identified risk.

Signal Detection. Signal detection technology employing a combination of threshold detection and signal parameter pattern recognition, as currently used by U-NII DFS devices operating in the 5250-5350 MHz and 5470-5725 MHz bands, is designed to detect pulsed radar signals (parameters shown in Appendix A). The digital DSRCS signals will have different spectral characteristics as compared to the pulsed radar signals currently being detected by U-NII DFS-enabled devices. In addition, DSRCS OBUs are mobile which may complicate signal detection. NTIA, in conjunction with DOT and industry representatives, will determine whether they can use or adapt existing signal detection techniques for sharing with radar systems or the techniques for sharing between U-NII devices to detect ground-based and airborne DSRCS signals to address the identified risk.

Geo-Location. The FCC regulations for U-NII DFS devices and the IEEE 802.11ac standard do not address geo-location spectrum-sharing technology. To implement geo-location technology, a database of DSRCS RSU transmitter and receiver locations around which protection distances and/or frequency restrictions are established could be developed.[96] It may be possible to use frequency relationships between the RSU transmitters to protect mobile OBU receivers.[97] Many of the database management and authorization issues that the FCC had to address with the TVBDs would have to be addressed if geo-location technology is implemented to protect federal DSRCS systems. NTIA, in conjunction with DOT, the transportation community and wireless industry representatives, will need to examine in more detail whether they could use geo-location spectrum-sharing technology to mitigate the risks associated with ability of signal sensing spectrum-sharing technologies to protect DSRCS operations.

Risk Element 3 - Current U-NII Regulations Were Not Developed to Protect Non-Co-Located Transmitter and Receiver

The existing U-NII regulations were developed specifically to protect radar receivers from interference where the transmitter and receiver are co-located. The DSRCS has RSU stations in fixed locations and OBU stations located on automobiles. Transmitters and receivers operating at different locations introduce a new sharing situation referred to as the “hidden node” problem. As

[96] A change in the existing FCC rules may be needed in order to develop a database of DSRCS RSU transmitter and receiver locations.

[97] There are OBU receivers associated with RSUs and OBU receivers that operate independent of an RSU.

discussed in the evaluation of the 5350-5470 MHz band, it may be possible to use known frequency relationships between the DSRCS RSU and OBU transmitters and receivers to address the “hidden node” problem. If the DSRCS RSU and OBU transmitter/receiver operating frequency information does not change, it could be provided in a look-up table or specified on a geographic basis using a database in conjunction with geo-location technology. NTIA will work with DOT, the wireless industry, the transportation community and the FCC to gather additional DSRCS transmitter and receiver frequency information. NTIA will also work with wireless and transportation industry representatives to determine if they are able to implement this approach or have alternative solutions to address the identified risk associated with the “hidden node” problem.

Risk Element 4 - Changes to U-NII DFS Detection Parameters May Not Protect Systems from Serious Degradation

The ability of DFS signal sensing spectrum-sharing technologies to detect digital DSRCS signals is not known at this time. Laboratory and field measurements will be required to evaluate the capability to detect DSRCS signals. NTIA, in conjunction with the DOT and other stakeholders, will develop representative test waveforms for laboratory measurements to verify DFS detection capabilities. To address this risk, the new waveforms will be used in laboratory testing of prototype devices. Depending on the results of the laboratory measurements, validation of the effectiveness of any proposed changes to the U-NII regulations may require testing with an operational DSRCS system to address this risk.

ADDITIONAL SAFEGUARDS TO FACILITATE SPECTRUM-SHARING ARRANGEMENTS

The U-NII devices in the 5725-5825 MHz band are authorized to operate at higher EIRP levels, employ high-gain directional antennas, and are not required to employ DFS spectrum-sharing technology (see Table 3-1). The higher EIRP levels and directional antennas are used for longer-range outdoor point-to-point U-NII device applications. A quantitative analysis would need to consider what limitations on the technical and deployment characteristics of U-NII devices, if any, would be required to ensure compatibility with the federal systems. This analysis would examine whether the identified risk to federal radar systems in the 5850-5925 MHz band and DSRCS systems in the 5850-5925 MHz band could be mitigated if U-NII devices were limited to the lower density point-to-point applications currently operating in the 5725-5825 MHz band. If those limitations prove necessary, they will determine the types of U-NII devices that are suitable for operation in this band.

In many cases, the federal radar systems operating in the 5850-5925 MHz band are the same as those operating in the 5725-5825 MHz band currently authorized for U-NII devices.[98] The band 5725-5875 MHz, which overlaps the 5850-5925 MHz band, is also designated internationally for industrial, scientific, and medical (ISM) applications. Thus, federal radar systems operating within

[98] Many radar systems are designed to operate across the entire 5250-5925 MHz band.

this band outside the United States and Possessions (US&P) must accept harmful interference that may be caused by ISM devices.[99] In addition to the ISM applications, low-powered unlicensed devices using digital and spread spectrum techniques are permitted in the 5725-5850 MHz band.[100] Federal radar systems operating throughout the 5725-5925 MHz band currently co-exist with lower density point-to-point U-NII devices as well as ISM and other unlicensed devices. A quantitative analysis would show whether the risks to federal radar systems would be addressed by extending the existing 5725-5825 MHz band U-NII regulations to the 5850-5925 MHz band. The quantitative analysis will also need to examine if additional technical constraints on U-NII devices operating in the 5850-5925 MHz band are necessary to protect federal radar systems.

Similar to the federal radar systems, DSRCS, ISM, and low-powered unlicensed devices share portions of the 5850-5925 MHz band. In addition to these systems, DSRCS systems when deployed would have to co-exist with high-powered pulsed radar systems that operate throughout the band.[101] A quantitative analysis will need to examine if the risks to DSRCS systems are addressed by extending the existing 5725-5825 MHz band U-NII regulations to the 5850-5925 MHz band. An analysis will also need to examine if additional technical constraints on U-NII devices operating in the 5850-5925 MHz band are necessary to protect DSRCS systems. As discussed earlier, the IEEE 802.11p standard is used for the physical layer application for the wireless connectivity using DSRCS. The analysis will also need to consider whether using the RF physical layer of the IEEE 802.11ac standard would improve sharing between U-NII devices and DSRCS systems.[102]

[99] The ISM frequency bands are radio bands reserved internationally for the use of RF energy for industrial, scientific, and medical purposes other than communications. Examples of applications in these bands include radio-frequency process heating, microwave ovens, and medical diathermy machines. The emissions of these devices can create electromagnetic interference and disrupt radio communication using the same frequencies, so these devices were limited to certain bands of frequencies. In general, communications equipment operating in these bands must tolerate any interference generated by ISM equipment, and users have no regulatory protection from ISM device operation. *See* 47 C.F.R. § 18.111.

[100] *See* 47 C.F.R. §§ 15.247.

[101] The coordination zones around the radar installations specified in the FCC rules were established to protect the radar systems, not the DSRCS systems.

[102] The RF physical layer defines the air interface used to transmit data.

SECTION 6. CONCLUSIONS

The analysis contained in this report identifies a number of risks to federal radiocommunication systems, spaceborne sensors operated by the United States and other countries, and transportation systems, associated with allowing U-NII devices to operate in the 5350-5470 MHz and 5850-5925 MHz bands. Elements associated with these risks arise in part because of the underlying condition that the current U-NII DFS device regulations that are applicable in the bands 5250-5350 MHz and 5470-5725 MHz can be used to protect systems operating in the 5350-5470 MHz and 5850-5925 MHz bands. The risks associated with each category of system summarized in Table 6-1 have been identified.

Table 6-1. Summary of Risk Elements Associated with U-NII Devices Operating in the 5350-5470 MHz and 5850-5925 MHz Bands

System Category	Frequency Band (MHz)	Description of Risk Element
Radar Systems	5350-5470 and 5850-5925	• Changes in radar signal parameters may impact U-NII device detection of radar systems. • Changes in U-NII device deployment and technical parameters may result in harmful interference. • Existing U-NII regulations may not adequately protect current and future radar systems from serious degradation. • Changes to U-NII DFS detection parameters may not protect current and future radar systems from serious degradation. • Existing U-NII regulations may introduce “hidden node” interference. • U-NII devices operating on adjacent channels may cause harmful interference to radar systems. • Radar receiver interference protection criteria used to develop existing U-NII DFS regulations may not address low-level interference effects. • Channel response time requirements in the current DFS regulations may not be adequate to protect all radar system operational scenarios.
Airborne Systems	5350-5470	• Existing U-NII regulations were not developed to detect airborne signals. • U-NII signal detection technologies may not be capable of detecting airborne signals resulting in serious performance degradation. • Current U-NII DFS regulations were not developed to protect transmitters and receivers in different locations. • Changes to U-NII DFS detection parameters may not protect airborne operations from serious performance degradation.

Table 6-1. Summary of Risk Elements Associated with U-NII Devices Operating in the 5350-5470 MHz and 5850-5925 MHz Bands (Continued)

Synthetic Aperture Radar Systems	5350-5470	• Existing U-NII regulations were not developed to protect spaceborne receivers.
Dedicated Short Range Communication Service (DSRCS) Systems	5850-5925	• Existing U-NII regulations were not developed to detect DSRCS signals. • U-NII signal detection technologies may not be capable of detecting DSRCS signals. • Current U-NII regulations were not developed to protect transmitters and receivers in different locations. • Changes to U-NII DFS detection parameters may not protect DSRCS systems from serious performance degradation.

Notwithstanding the significant technical challenges surrounding the potential introduction of U-NII devices in these bands, NTIA concludes that further analysis is required to determine whether and how the risk factors can be mitigated through, for example, by the promulgation of new safeguards in addition to the FCC's existing requirements. Accordingly, NTIA, in collaboration with the federal and industry stakeholders and the FCC, will conduct quantitative analysis of potential mitigation requirements in connection with regulatory proceedings. NTIA will continue to collaborate with other federal agencies and industry stakeholders to further assess the feasibility of existing, modified, and new spectrum sharing technologies and approaches. This analysis will be more complex than that used to develop the existing U-NII DFS/TPC regulations, because the number of sharing scenarios between U-NII devices and federal systems is greater and the practical limitations of using existing or modified spectrum-sharing technologies to protect different types of operations and platforms (*i.e.*, airborne systems, spaceborne sensors, and DSRCS devices) need to be assessed and evaluated. In addition, the interference to TDWR demonstrates the importance of the FCC certification and enforcement processes that must be taken into consideration to effectively preclude harmful interference if U-NII device operations are authorized in the 5350-5470 MHz and 5850-5925 MHz bands.

While the state-of-the-art of existing and proposed spectrum sharing technologies is advancing at a rapid pace, NTIA recognizes the importance of these bands to the federal agencies, international satellite-sensor data users, and the transportation industry and the potential risks of introducing a substantial number of new, unlicensed devices into them without proper safeguards. As the Tax Relief Act requires, the FCC and NTIA must determine that licensed users will be protected by technical solutions and that the primary mission of federal spectrum users will not be compromised before adopting service rules authorizing U-NII devices in the 5350-5470 MHz and 5850-5925 MHz bands.

SCHEDULE AND MILESTONES FOR QUANTITATIVE STUDY

International Telecommunication Union-Radiocommunication Sector (ITU-R) Joint Task Group (JTG) 4-5-6-7 is responsible for the broadband agenda item for the 2015 World Radiocommunication Conference (WRC-15).[103] The domestic work contained in this report focuses on a qualitative evaluation of the risks associated with allowing U-NII devices access to the 5350-5470 MHz and 5850-5925 MHz bands. The international work will be performed under the State Department International Telecommunication Advisory Committee (ITAC)-R.[104] This work must be consistent with the domestic studies and will include identifying incumbent and U-NII system characteristics and performing more detailed quantitative studies (analysis and measurements) to fully address the risks identified in this study and determine under what specific conditions sharing may be possible. Table 6-2 provides a tentative schedule and milestones for completion of the quantitative evaluation. This schedule would enable timely reporting of U.S. findings to JTG 4-5-6-7.

Specifically, all JTG 4-5-6-7 studies must be finalized by the end of 2014 in preparation for WRC-15. However, because studies and regulatory activities required by the Tax Relief Act contemplate unlicensed operations that would be authorized only in the United States, there is a chance that these matters may not ultimately be on the WRC agenda. Adoption of standards in the ITU-R for unlicensed device operation in either the 5350-5470 MHz or 5850-5925 MHz bands could benefit both industry and the U.S. Government if the result adequately protects incumbent services and does not compromise the mission of federal spectrum users. Joint industry and government efforts in connection with WRC-03 led to a world-wide allocation for wireless access systems in other parts of the 5 GHz band, and this was vital to the successful completion of the FCC's original U-NII rulemaking.

NTIA is already working with the affected federal agencies to bring the incumbent and U-NII system characteristics into the ITU-R study process and complete the analysis and measurements identified in this study. This approach will best position the United States for work in the ITU-R as other countries will inevitably bring forward studies on these bands.

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[103] The JTG 4-5-6-7 has representatives from ITU-R Study Groups 4, 5, 6, and 7.

[104] The general guidance for the ITAC is *available at* http://transition.fcc.gov/ib/sand/irb/guidance.html.

Table 6-2. Tentative Schedule and Milestones for Completing Quantitative Evaluation

Tentative Schedule[a]	Number of Months	Milestones
January 2013 to March 2013	3	- Review existing analysis methodology documented in NTIA Technical Memorandum 09-461 and identify areas where modifications are necessary. - Define technical characteristics of federal systems operating in 5350-5470 MHz and 5850-5925 MHz bands. - Define U-NII device deployment and technical parameters. - Review existing sharing scenarios between federal systems and U-NII devices and make necessary modifications or develop new sharing scenarios. - Perform initial analysis of limiting sharing scenarios to define modeling considerations for more detailed simulation analysis. - Participate in FCC rulemaking proceeding called for in the Tax Relief Act.
April 2013 to May 2013	2	- Validation of NTIA simulation analysis model. - Review of NTIA simulation analysis model results for different sharing scenarios. - Develop supporting material for 5 GHz international study. - Participate in FCC rulemaking proceeding called for in the Tax Relief Act.
June 2013 to July 2013	2	- Develop initial recommendations on suitability of the 5350-5470 MHz and 5850-5925 MHz bands for U-NII device operations. - Document initial analysis and modeling assumptions and sharing results. - Participate in FCC rulemaking proceeding called for in the Tax Relief Act.
August 2013 to October 2013	3	- Revise as necessary the analysis and modeling assumptions based on feedback from international meeting. - Document the results of revised sharing studies. - Participate in FCC rulemaking proceeding called for in the Tax Relief Act.
November 2013 to June 2014	8	- Revise as necessary the analysis and modeling assumptions based on feedback from international meeting. - Document the results of revised sharing studies. - Identify measurements necessary to verify U-NII DFS performance - Perform laboratory measurements as necessary - Perform field measurements as necessary - Document laboratory and field measurements - Participate in FCC rulemaking proceeding called for in the Tax Relief Act.
July 2014 to December 2014	6	- Finalize recommendations for international study - Finalize recommendations to the FCC

Note a: The dates in this schedule are tentative because delays can occur during the different stages of the review and coordination process and can impact completing the milestones. Equipment availability is beyond the control of NTIA and would also impact completing the milestones.

APPENDIX A

RADAR TEST WAVEFORMS

INTRODUCTION

This appendix describes the radar waveforms used by the Federal Communications Commission in the compliance measurement procedures for Dynamic Frequency Selection (DFS) tests under Part 15 Subpart E Rules required for Unlicensed-National Information Infrastructure (U-NII) equipment that operates in the frequency bands 5250-5350 MHz and/or 5470-5725 MHz.

RADAR TEST WAVEFORMS

The test waveforms used in the certification tests of U-NII DFS enabled devices were developed based on the technical characteristics of the existing and future radar systems operating in the 5 GHz frequency range.

Table A-1 provides the short pulse radar test waveforms.

Table A-1. Short Pulse Radar Test Waveforms

Radar Type	Pulse Width (μsec)	Pulse Repetition Interval (μsec)	Number of Pulses
1	1	1428	18
2	1-5	150-230	23-29
3	6-10	200-500	16-18
4	11-20	200-500	12-16

Table A-2 provides the long pulse radar test waveform.

Table A-2. Long Pulse Radar Test Waveform

Radar Type	Pulse Width (μsec)	Chirp Width (MHz)	Pulse Repetition Interval (μsec)	Number of Pulses per Burst	Number of Bursts
5	50-100	5-20	1000-2000	1-3	8-20

Table A-3 provides the frequency hopping radar test waveform.

Table A-3. Frequency Hopping Radar Test Waveform

Radar Type	Pulse Width (µsec)	Pulse Repetition Interval (µsec)	Pulses Per Hop	Hopping Rate (kHz)	Hopping Sequence Length (msec)
6	1	333	9	0.333	300

APPENDIX B

ASSESSMENT OF UNLICENSED-NATIONAL INFORMATION INFRASTRUCTURE DEVICE DEPLOYMENT AND TECHNICAL PARAMETERS

INTRODUCTION

To determine the necessary Dynamic Frequency Selection (DFS) detection thresholds, NTIA developed a computer model that calculated the aggregate interference level into a radar system from a deployment of Unlicensed-National Information Infrastructure (U-NII) devices.[105] The computer model took into account the deployment and technical parameters associated with U-NII devices and performed link budget calculations to determine the effect of U-NII devices employing the DFS sharing technology and the aggregate level of U-NII device signals that would be received by the radar systems.

This appendix provides an assessment of the U-NII device deployment and technical parameters for use in evaluating the risks to federal systems operating in the 5350-5470 MHz and 5850-5925 MHz bands. This assessment compares the U-NII device deployment and technical parameters used in the development of the existing FCC U-NII regulations with those inputs to this study provided by industry representing current and projected usage in the 5 GHz frequency bands authorized for U-NII devices.

U-NII DEPLOYMENT TECHNICAL AND OPERATIONAL PARAMETERS USED IN DEVELOPING EXISTING REGULATIONS

The analysis used to develop the existing U-NII regulations, distributed U-NII devices over three regions: urban, suburban, and rural. The urban region reflected the corporate and public access use of U-NII devices. The suburban region reflected corporate, public access, and home U-NII device use. The rural region reflected only home U-NII device use. The analysis method assumed that the three regions exist within concentric circles as shown in Figure B-1.

[105] NTIA Technical Memorandum TM-09-461.

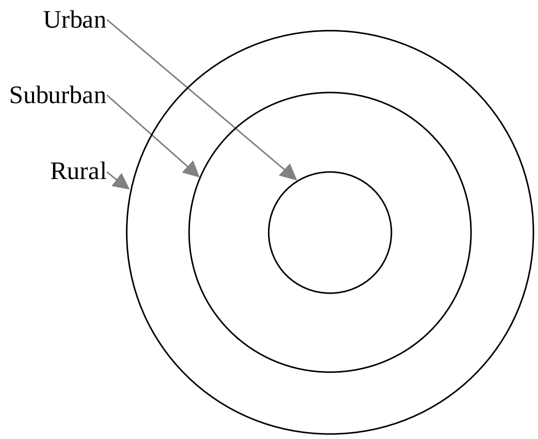

Figure B-1. U-NII Device Deployment Regions

NTIA utilized three concentric rings to define the U-NII device deployment as shown in Table B-1. Uniform distribution of devices in each zone was utilized throughout each volumetric zone including height.

Table B-1. U-NII Device Deployment Parameters

Deployment Parameter	Urban zone	Suburban zone	Rural zone
Radius from the Center (km)	0-4	4-12	12-25
U-NII Device (%)	60	30	10
Building Height (m)	30	6	6

A total of 2,753 U-NII devices operating on a co-channel basis with a radar system at a given moment were utilized. All of the U-NII devices considered in the analysis were assumed to have a radio frequency (RF) channel bandwidth of 20 MHz.

The U-NII device power distribution in Table B-2 was utilized.

Table B-2. U-NII Device Power Distribution

Power Level	1 W	200 mW	100 mW	50 mW
U-NII Device (%)	5	25	40	30

The U-NII antenna pattern in the azimuth orientations is omnidirectional. The U-NII device elevation antenna pattern is described in Table B-3.

Table B-3. U-NII Device Elevation Antenna Pattern

Elevation Angle θ (Degrees)	Gain (dBi)
45 < θ ≤ 90	–4
35 < θ ≤ 45	–3
0 < θ ≤ 35	0
–15 < θ ≤ 0	–1
–30 < θ ≤ –15	–4
–60 < θ ≤ –30	–6
–90 < θ ≤ –60	–5

In order for most devices to radiate with 1 Watt equivalent isotropically radiated power (EIRP), an antenna gain of 6 dBi will typically be required. The following antenna pattern from Recommendation ITU-R F.1336 was used:[106]

$$G(\theta) = \max\left[G_1(\theta), G_2(\theta)\right]$$

$$G_1(\theta) = G_0 - 12\left(\frac{\theta}{\theta_3}\right)^2$$

$$G_2(\theta) = G_0 - 12 + 10\log\left[\left(\max\left\{\frac{|\theta|}{\theta_3}, 1\right\}\right)^{-1.5} + k\right]$$

$$\theta_3 = 107.6 \times 10^{-0.1G_0}$$

where:

$G(\theta)$: antenna gain (dBi)

θ: elevation angle (degrees)

$k = 0.5$

$G_0 = 6$ dBi.

The methodology used to determine the probability of a radar signal being detected during the DFS device channel sensing time based on the radar parameters and the U-NII data transmissions is described in Annex 4 of Recommendation ITU-R M.1652.[107]

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106 Recommendation ITU-R F.1336, *Reference Radiation Patterns of Omnidirectional and Other Antennas in Point-to-Multipoint Systems for Use in Sharing Studies* (1997).

107 Recommendation ITU-R M.1652, *Dynamic Frequency Selection (DFS) in Wireless Access Systems Including Radio Local Area Networks for the Purpose of Protecting the Radiodetermination Service in the 5 GHz Band* (2003).

RECOMMENDATIONS FOR TECHNICAL AND DEPLOYMENT PARAMETERS OF U-NII DEVICES OPERATING IN THE 5350-5470 MHz AND 5850-5925 MHz BANDS

NTIA sought initial input from a group of industry representatives from companies that are interested in expanding unlicensed use of the 5 GHz band in support of IEEE 802.11ac related to the deployment and technical parameters to be used in assessing the potential interference to federal systems if U-NII devices that would be operating in the 5350-5470 MHz and 5850-5925 MHz bands.[108]

U-NII Device Deployment Parameters

The following subsections provide the methodology used by industry to determine the total number of U-NII device transmitters to be considered in the analysis.[109]

Determine population size. From ITU-R Recommendation F.1509, the radius of the total deployment zone is a function of total population as follows:[110]

$$r_R = \alpha P^{\beta} \qquad \text{B-1}$$

where:

r_R: Radius of the equivalent circular area containing the total population P;

P: Total population;

α, β: Empirical factors, $\alpha = 0.035$ and $\beta = 0.44$.

NTIA defined the radius of the total deployment zone as 25 km. Solving for the total population results in:

$$P = \exp\left(\frac{\ln\left(r_R/\alpha\right)}{\beta}\right) \qquad \text{B-2}$$

Total population based on Equation B-2 is approximately 3 million.

Population split between environments. Based on latest available information, the wireless industry representatives selected the population split as given in Table B-3. The resulting population in each region is 919,000 in urban, 1.5 million in suburban, and 612,000 in rural. Within

[108] Letter from Mary L. Brown, Director, Government Affairs, Cisco Systems, Inc. to Karl Nebbia, Associate Administrator, Office of Spectrum Management, NTIA (Sept. 26, 2012).

[109] For U-NII devices employing multiple-input and multiple-output (MIMO) techniques, the analysis should evaluate total EIRP summed over all antennas.

[110] Recommendation ITU-R F.1509, *Technical and operational requirements that facilitate sharing between point-to-multipoint systems in the fixed service and the inter-satellite service in the band 25.25-27.5 GHz* (2001).

each region, the type of deployments is split into corporate, public access, and residential. The RLAN aggregation model defines the places where RLANs transmit.

Table B-3. Population Distribution

Environment	Population (%) (P_E)	Population (%) (P_D)
Urban	30	
Corporate		35
Public Access		15
Residential		50
Suburban	50	
Corporate		35
Public Access		15
Residential		50
Rural	20	
Residential		100

The premise of corporate deployments is the corporate System Factor and corporate Activity Rate reflects that the RLANs and their transmissions are managed to meet work requirements, not for watching YouTube. The corporate population is the percent of population using Wi-Fi in corporate locations.

The premise of public access deployments is the System Factor and Activity Rate reflect that the RLAN access points (AP) are older, there are more active users per AP, and the streaming content comes from less expensive wired Internet connection, not a gigabit Internet connection. The public access population is the percent of population using Wi-Fi not at home and not in a corporate location.

The premise of residential deployments is the small System Factor and Activity Rate reflect that the RLAN APs are older, there are few people in the residence, and the streaming content comes from a relatively less expensive wired connection compared to corporate Internet connections. RLANs used for work-from-home and student homework in the residential population are included.

Market penetration of 5 GHz. Market penetration indicates the percentage of the population that use wireless access systems (WAS). Furthermore, the majority of current Wi-Fi usage is in 2.4 GHz, especially in public access. New use cases will likely increase the market adoption of 5 GHz technology. However, a significant percentage of WAS traffic will remain at 2.4 GHz. Therefore, market penetration in Table B-4 is the percentage of population that use WAS in 5 GHz.

Table B-4. 5 GHz Market Penetration

Environment	**Market Penetration of 5 GHz (%) (M)**
Corporate	80
Public Access	30
Residential	50

System factor. Multiple people will be covered by a single AP in a basic service set (BSS). In addition, each person has multiple devices, *e.g.*, laptop, smart phone. Only one device or the AP will be transmitting at a given instant. The system factor parameter determines the ratio of the user's devices to an access point. As seen in Table B-5, residential has a much smaller system factor to account for peer-to-peer connections in the home.

Table B-5. System Factor

Environment	**System Factor (S)**
Corporate	20
Public Access	25
Residential	5

Activity Rate. Consumers need larger bandwidth and higher data rates to support fast file transfer and video. However, over a large geographic area, it is highly unlikely that every BSS will simultaneously be engaging in these applications. Furthermore, public access systems are limited by their backhaul, reducing the aggregate access to the Internet. For example, while an 802.11ac AP may support 1 gigabits per second traffic within a local coffee shop, its 10 megabits per second Internet connection will significantly limit the over-the-air activity to 1 percent. Industry modeled residential activity at 5 percent because they expect the UNII device data rates to increase as affordable broadband access speeds increase. Table B-6 provides predicted activity rates.

Table B-6. Predicted Activity Rates

Environment	Activity Rate (%) (A)
Corporate	15
Public Access	5
Residential	5

Computation of active users. The number of active users (U) in each region is computed by Equation B-3.

$$U = P \cdot P_E \cdot P_D \cdot M \cdot {}^{1}\!/_{S} \cdot A \qquad \text{B-3}$$

The total number of active users in the geographic area is summed over the entire region. This is illustrated in Table B-7, with a total of 14,553 active users.[111]

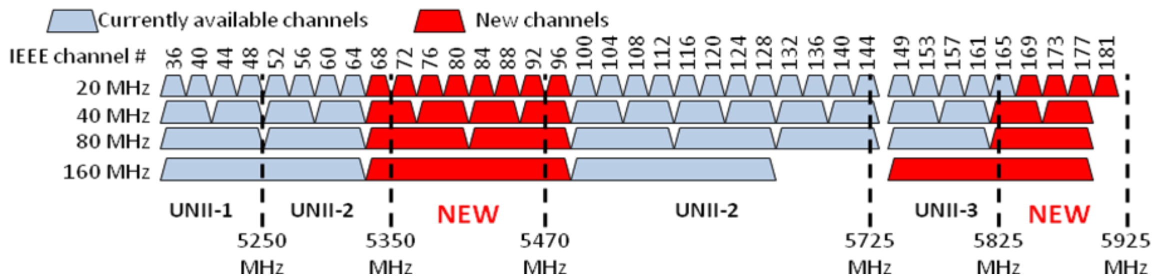
Table B-7. Computation of Active Users

	Radius (km)	Population Type Split (%)	Population	WAS Users = pop(market penetration)	BSS per region = (WAS users)/(system factor)	Total Active WAS users per region = (BSS per region)(active rate)
Urban	4		918742.7			
	Corporate	35	321559.9	257248	12862.4	1929.4
	Public	15	137811.4	41343.4	1653.7	82.7
	Residential	50	459371	229686	45937	2297
Suburban	12		1531237.8			
	Corporate	35	535933.2	428746.6	21437.3	3215.6
	Public	15	229685.7	68905.7	2756.2	137.8
	Residential	50	765618.9	382809.5	76561.9	3828.1
Rural	25		612495.1			
	Residential	100	612495.1	306247.6	61249.5	3062.5
Total						14,553

Distribution of active users over 5 GHz channels. If interference from adjacent channels is included in the sharing analysis with federal systems, it is necessary to populate the prospective active users across all of the available 5 GHz channels to capture the adjacent channel interference. Figure B-2 illustrates the IEEE 802.11ac channels in currently authorized and available U-NII and

111 The industry input contained an error in the residential population for the urban residential region. The number provided by industry was 160,780. The correct number is 459,371. This changes the number of total active users from 13,060 to 14,553.

unlicensed bands along with the potential new channels (shown in red) that could result if 5350-5470 MHz and 5850-5925 MHz bands are made available.[112]



UNII-1: 5150-5250 MHz band

UNII-2: 5250-5350 MHz and 5470-5725 MHz band

UNII-3: 5725-5825 MHz band

Figure B-2. Distribution over 5 GHz Channels

It would be assumed that active users are uniformly distributed across all of the currently available channels and new channels 68-96 and 169-181. For each active user, the channel bandwidth would be based on the distribution in Table B-10 and a channel number would be selected with a uniform distribution from the available channels shown in Figure B-2.

Three Concentric Rings to Define the U-NII Device Deployment

The metro device distribution of 50 percent suburban population and 20 percent rural population matches U.S. metro populations reported by the U.S. Census Bureau.[113] Within each zone, nearly 10 percent of U-NII devices are operated outdoors near ground level, including operation in vehicles, or are co-located on street lighting and strand mounts above streets. A very small fraction of all U-NII devices are operated outdoors on rooftops or towers in point-to-multipoint or bridging configurations. The fraction of all U-NII devices is lower in the urban zone because there is much more fiber and microwave to buildings or near buildings than in the rural zone.

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[112] This figure was presented in https://mentor.ieee.org/802.11/dcn/12/11-12-1159-03-00ai-masers-slaves-and-clients.pptx.

[113] United States Census Bureau publication http://www.census.gov/prod/2002pubs/censr-4.pdf , at 33. Furthermore, http://www.census.gov/geo/www/ua/2010urbanruralclass.html and http://www.fhwa.dot.gov/planning/census_issues/archives/metropolitan_planning/cps2k.cfm also report 20 percent rural population, and http://www.pbs.org/fmc/book/1population6.htm reports 50 percent suburban population.

Table B-8. U-NII Device Distribution

U-NII Device Distribution Parameters	Urban Zone	Suburban Zone	Rural Zone
Radius from the Center	0-4 km	4-12 km	12-25 km
U-NII Device Percentage (Indoor Operation)	27%	45%	18%
U-NII Indoor Maximum Height	30 m	6 m	6 m
U-NII Device Percentage (Outdoor Ground Clutter; less than 12 m)	2.9%	4.8%	1.7%
U-NII Device Percentage (Outdoor Operation; outdoor bridging)	0.1%	0.2%	0.3%
Outdoor Point-to-Multipoint bridging: Maximum Building/ Antenna Height	100 m	30 m	30 m

U-NII Device Technical Parameters

The U-NII device EIRP levels are provided in Table B-9.

Table B-9. U-NII EIRP Distribution – EIRP when operating

U-NII EIRP Level	1 W	200 mW	80 mW	50 mW	25 mW
U-NII Device Percentage (Indoor Operation)	0%	16.9%	50.6%	13.4%	9.1%
U-NII Device Percentage (Outdoor Ground Clutter; less than 12m)	0%	1.7%	5.3%	1.4%	1%
U-NII Device Percentage (Outdoor Operation; outdoor bridging)	0.6%	0%	0%	0%	0%
The EIRP in this table reflects what the actual transmit powers are likely to be, and that these in many cases will be below maximum power allowed based on adjusting the transmit power for capacity versus coverage. TPC therefore does not need to be separately modeled for the purposes of the analysis.					

The EIRP levels and percentages in Table B-9 are derived from: 1) predictions of shipped devices for various devices classes; 2) expected EIRP of the device classes; 3) matching the percentages from the sum of the rows in Table B-8 to Table B-9; and 4) traffic mix in a Basic Service Set between Access Point and client.

The industry representatives have suggested that the ITU-R model (as used in the current NTIA aggregate interference simulation) gives a good approximation to typical antenna patterns and they recommend continuing to use ITU-R model.

The U-NII device bandwidths are contained Table B-10.

Table B-10. U-NII Device Bandwidth Distribution (Projected Bandwidth)

U-NII Transmitter Bandwidth	20 MHz	40 MHz	80 MHz	160 MHz 80 MHz and 80 MHz (non-contiguous)
Percentage of U-NII Devices	10%	25%	50%	15%

The percentages in Table B-10 are based on experience from the transition from 20 MHz to 40 MHz channels in 802.11n.

The representative emission spectra for U-NII device bandwidths of: 20 MHz, 40 MHz, 80 MHz, and 160 MHz (80 MHz and 80 MHz non-contiguous) are provided in Table B-11.

Table B-11. Representative Emission Spectra for U-NII Devices

Frequency Offset From RF Chanel Center Frequency (MHz)	Emission Level (dBr)
± BW/2-1	0
± BW/2+1	-20
± BW	-28
± 3/2*BW	-45
± 2*BW	-52
Transmit emission mask for 20/40/80/160 MHz BW operation.	

The emission levels at BW/2-1, BW/2+1, and BW are quoted from IEEE 802.11ac D2.0. The emission levels for 3/2*BW and 2*BW were determined by measurements from "Revision of Part III of U-NII to TDWR EMC Report."[114] These were further confirmed by several manufacturers as a reasonable representation of the emissions of IEEE 802.11ac devices.

Recommendation ITU-R M.1652 Annex 4 describes the methodology used to determine the probability of a radar signal being detected during the DFS device channel sensing time based on the radar parameters and the U-NII data transmissions. This methodology did not take into consideration the higher data rates envisioned by the IEEE 802.11ac standard. The industry group recommended a revision for *Step 3* in ITU-R M.1652 Annex 4, to generalize the method to cover all possible frame sizes that are allowed by recent IEEE 802.11 amendments. The revision is described below:

[114] NTIA Case Study Part III at 8 and 9.

Revised Step 3: Create a waveform to represent WAS transmit time and listening periods using the values in Table B-12a, B-12b, B-12c, and B-12d. Table B-12a shows the Enhanced Distributed Channel Access (EDCA) categories. The chance of each access category occurring is shown the second column. For each access category a transmit opportunity (TXOP) phase is assumed where a station may transmit as many PHY-layer packets, up to the defined duration of the TXOP. Figure B-3 shows an example of PHY-layer packets exchanges in a TXOP. When a TXOP finishes, stations that want to access a channel need to go through contention procedures that would create quiet periods with random durations. The quiet periods for each access category are shown in the third column of Table B-12a. The default TXOP durations for each access category, according to IEEE 802.11ac specification, are shown in the fourth column. Note that for access categories BE and BK no default value is recommended in the specification. Instead a single PHY-layer packet is transmitted, whose duration is obtained from Table B-12b, B-12c, and B-12d for each of the allowed bandwidths. The PHY-layer packet duration in Table B-12b, B-12c, and B-12d is an aggregation of several MAC-layer packets where each MAC-layer packet has a single TCP packet of size 1,500 bytes plus associated MAC-layer overhead.

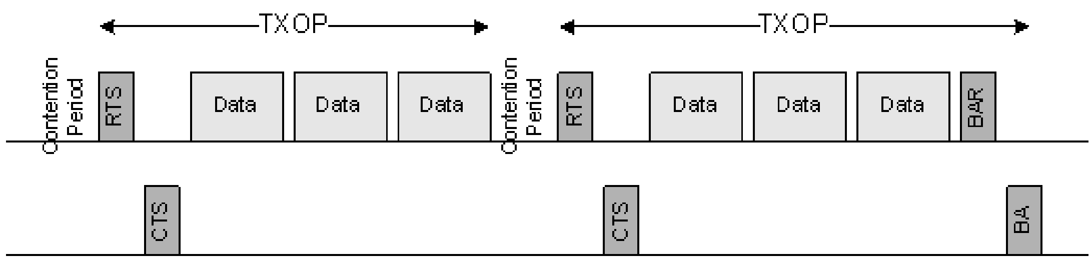

Figure B-3.[115]

In a TXOP, the station that owns the TXOP may send several PHY-layer packets to one or more stations and might seek a response, such as acknowledgment, from each station.

The WAS transmit waveform for each instance of a WAS packet transmission is created by randomly choosing an access category according to the distribution in the second column of Table B-12a. First a quiet period starts that is required by the WAS network to facilitate sharing of the access medium (*i.e.* the WAS channel) by the multiple devices using the network. This quiet period is available for in-service monitoring. The quiet period is chosen according to the third column of Table B-12a. Then single or multiple PHY-layer packet exchanges are followed. The duration of TXOP for access categories VO and VI are given in the fourth column of Table B-12a. For access categories BE and BK, a single PHY-layer packet, with duration given in Table B-12b, B-12c, and B-12d, is transmitted, where a duration is drawn uniformly from the table with appropriate bandwidth. Then another access category is chosen randomly in the same manner as the first, starting with another quiet period following with PHY-layer packet exchanges. This is repeated until the

[115] This figure is reproduced with permission from Perahia, E. and Stacey, R., "Next Generation Wireless LANs: Throughput, Robustness, and Reliability in 802.11n," Cambridge University Press (2008).

waveform has the same duration as that of a WAS device in the main beam of the antenna, as calculated in Step 1.

Table B-12a: EDCA access categories and associated quiet periods (combined IFS and defer time)

EDCA Access Category	Access Category Probability	Quiet Period (us) U(Y) is uniform distribution for integers 1 to Y	11ac Default TXOP duration (us)
Voice (VO)	0.1	AIFS[VO]+Backoff = 34 + U(15) x 9	1,504
Video (VI)	0.5	AIFS[VI]+Backoff = 34 + U(31) x 9	3,008
Best effort (BE)	0.2	AIFS[BE]+Backoff = 43 + U(1023) x 9	See Note
Background (BK)	0.2	AIFS[BK]+Backoff = 79 + U(1023) x 9	See Note

Note: For BE and BK access categories, one PHY-layer packet transmission is assumed after the associated quiet period. The PHY-layer packet duration is obtained from Table B-12b, B-12c, or B-12d.

Table B-12b: PPDU duration in microsecond, for bandwidth 20 MHz, and 1/2/3 spatial streams (SS)

PPDU Duration (us)	MCS =0	MCS =1	MCS =2	MCS =3	MCS =4	MCS =5	MCS =6	MCS =7	MCS =8	MCS =9
SS=1, BW=20MHz	5,228	4,364	2,924	2,204	1,484	1,124	1,004	908	764	692
SS=2, BW=20MHz	4,368	2,208	1,488	1,128	768	588	528	480	408	372
SS=3, BW=20MHz	2,936	1,496	1,016	776	536	416	376	344	296	272

Note: TCP packets = 1,500 bytes. Aggregated MAC-layer packets =8,191 bytes. PHY-layer packet duration limit=5,484 us (max allowed in 802.11ac).

Table B-12c: PPDU duration in microsecond, for bandwidth 40 MHz, and 1/2/3 spatial streams (SS)

PPDU Duration (us)	MCS =0	MCS =1	MCS =2	MCS =3	MCS =4	MCS =5	MCS =6	MCS =7	MCS =8	MCS =9
SS=1, BW=40MHz	4,204	2,124	1,432	1,084	736	564	508	460	392	356
SS=2, BW=40MHz	2,128	1,088	740	568	396	308	280	256	224	204
SS=3, BW=40MHz	1,444	748	520	404	288	232	208	196	172	160

Note: TCP packets=1,500 bytes. Aggregated MAC-layer packets =8,191 bytes. PHY-layer packet duration limit=5,484 us (max allowed in 802.11ac).

Table B-12d: PPDU duration in microsecond, for bandwidth 80 MHz, and 1/2/3 spatial streams (SS)

PPDU Duration (us)	MCS =0	MCS =1	MCS =2	MCS =3	MCS =4	MCS =5	MCS =6	MCS =7	MCS =8	MCS =9
SS=1, BW=80MHz	1,964	1,004	684	524	364	284	256	236	204	188
SS=2, BW=80MHz	1,008	528	368	288	208	168	152	144	128	120
SS=3, BW=80MHz	696	376	268	216	160	136	124	120	108	104

Note: TCP packets=1,500 bytes. Aggregated MAC-layer packets =8,191 bytes. PHY-layer packet duration limit=5,484 us (max allowed in 802.11ac).

ASSESSMENT OF U-NII DEVICE DEPLOYMENT AND TECHNICAL PARAMETERS

Assessment of U-NII Device Deployment Parameters

The U-NII device deployment parameters that can potentially impact examining sharing with federal systems are the total number of U-NII devices and the distribution of U-NII devices.

In developing the existing FCC U-NII regulations, NTIA considered a total of 2,753 active U-NII devices in the sharing analysis. Taking into account factors such as population, 5 GHz market penetration, number of users per system, and activity rate, industry estimated there will be a total of 14,553 active 5 GHz U-NII devices. Although the number of active U-NII devices has increased by a factor of approximately six, this does not necessarily mean that the aggregate interference to federal systems will dramatically increase. If the DFS sharing technology is implemented properly, U-NII devices operating on the same RF channel as a federal system would detect the presence of a signal and change to another channel, turn off completely, or move to another frequency band (*e.g.*, 2.4 GHz). However, because the number of U-NII devices has increased, it could take longer for U-NII devices to move from an occupied channel, increasing the duration of interference to federal systems. With the increased number of U-NII devices, it is not possible to determine whether the DFS detection thresholds in the existing FCC U-NII regulations are adequate to reduce the magnitude and duration of the aggregate interference to federal systems. It will be necessary to perform additional computer modeling to determine whether the existing U-NII regulations are adequate to reduce the magnitude and duration of the potential aggregate interference to an acceptable level where sharing is possible with federal systems.

The U-NII device distributions used in the development of the existing DFS regulations and those provided by wireless industry representatives are shown in Table B-1 and Table B-7, respectively. In comparing the distributions of U-NII devices in the three zones (urban, suburban, and rural), industry is projecting lower U-NII device usage in the urban zone at 27 percent, as compared to the 60 percent used in the development of the DFS regulations. Industry is also projecting 15 percent higher U-NII device usage in the suburban zone. From an analytical perspective, the building/antenna heights and the amount of building attenuation are the parameters that will vary in the different zones defining U-NII device distribution. The computer model assumes that radio propagation loss and any additional losses due to building attenuation would be reciprocal. That is, any reduction in the signal strength from a radar to a U-NII device used for detection of an occupied RF channel would be the same when determining the signal strength from a U-NII device to a radar used in the calculation of interference. For a single U-NII device to radar interaction this relationship can be easily determined. However, when considering aggregate interference to federal systems, the proposed change will impact 10,478 U-NII device-to-radar interactions (72 percent of the 14,553 active U-NII devices). The density of U-NII devices is one of the key parameters in determining the amount of potential interference to the incumbent federal systems. It will be critical to establish a realistic U-NII device density before conducting the detailed technical analysis to accurately assess the impact of expanding access to the 5350-5470 MHz and 5850-5925 MHz bands. The impact of the changes in U-NII distributions on the DFS regulations that affect sharing with federal systems can only be evaluated through additional computer modeling.

Assessment of U-NII Device Technical Parameters

The U-NII device technical parameters that can potentially impact examining sharing with federal systems are the distribution of EIRP levels, distribution of RF channel bandwidths, and changes to the methodology used in detecting a radar signal.

The distribution of power levels considered in developing the existing U-NII regulations is shown in Table B-2. The distribution of EIRP levels provided by wireless industry representatives is shown in Table B-8. In order to convert the power levels in Table B-2 to EIRP levels, a 0 dBi antenna gain needs to be added to the values shown in Table B-2. As shown in Table B-2, 70 percent of the U-NII devices had an EIRP of 100 mW (20 dBm) or less. The industry input suggests that 73 percent of the U-NII devices have an EIRP of 80 mW (19 dBm) or less. In general, there is good agreement between the distribution of EIRP levels used in developing the U-NII regulations and those being suggested by industry.

The analysis performed to develop the existing U-NII regulations considered a single RF channel bandwidth of 20 MHz and assumed all of the 2,753 U-NII devices were operating co-channel with the radar system. The 20 MHz RF channel bandwidth was consistent with the IEEE 802.11h standard. With development of the IEEE 802.11n and IEEE 802.11ac standards, the channel bandwidths have increased to 40 MHz, 80 MHz, and 160 MHz as shown in Figure B-2. The wider RF channel bandwidths introduce new issues that could impact sharing with federal systems. In developing the existing U-NII regulations, the analysis model developed by NTIA assumed that when a U-NII device detected a radar signal, it moved off of that channel and far enough away in frequency so that it no longer contributed to the aggregate interference. However, during a recent investigation of interference from outdoor higher EIRP U-NII devices to the Terminal Doppler Weather Radar system, NTIA determined that some U-NII devices moved off of the channel, but still caused interference due to the transmitter out-of-channel emission levels being too high.[116] Wireless industry representatives provided representative emission spectra for U-NII devices in Table B-11 so this can be addressed in the analysis examining sharing with federal systems. NTIA will expand the methodology in NTIA Technical Memorandum 09-461 to include off-frequency interference from U-NII devices. This problem can be addressed by including a requirement in the U-NII regulations specifying a minimum frequency separation when a federal system is detected on an RF channel or specifying a transmitter emission mask. There are also questions regarding the DFS sensing capabilities associated with the wider bandwidth U-NII devices and the ability to detect off-frequency pulsed radar signals that will need to be addressed.

The computer model used to develop the existing U-NII regulations determines if the DFS detection threshold is exceeded for a particular U-NII device, generates a uniform random number, and compares it to the probability of a U-NII device detecting a radar signal, which is referred to as the probability of coincidence (POC). The POC is based on a combination of the probability of a radar signal being present and the probability of the U-NII DFS detection not being blocked by the DFS-equipped device being in a transmit mode. The POC expresses the probability that the DFS-equipped device is able to detect the radar signal when the radar signal is present. The time the radar signal is present is based on radar parameters such as 3 dB antenna beamwidth, antenna scan rate, pulsewidth, and pulse repetition interval. The time that the DFS-equipped U-NII device is capable of detecting a radar signal is based on the packet length and timing of the data transmissions. The model uses the parameters and methodology for calculating the POC described in Recommendation ITU-R M.1652. Industry representatives have recommended a change to the methodology contained in Recommendation ITU-R M.1652 to generalize the methodology to cover all possible frame sizes that are allowed by recent IEEE 802.11 amendments. NTIA needs to evaluate closely, the impact that this new methodology will have on the detection of the different

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[116] As an interim procedure to protect Terminal Doppler Weather Radar (TDWR) systems from interference, the FCC requires U-NII devices within 35 kilometers of a TDWR location to be separated by at least 30 MHz from the TDWR operating frequency. *See* http://apps.fcc.gov/kdb/GetAttachment.html?id=dV24P2kaxB%2BkKzIPZxHxHg%3D%3D. This problem has only been encountered with U-NII devices used for outdoor point-to-point applications.

types of signals used by federal systems operating in the 5350-5470 MHz and 5850-5925 MHz bands.

APPENDIX C
DETAILED DESCRIPTION OF DEPARTMENT OF DEFENSE 5 GHZ SYSTEMS

INTRODUCTION

The Department of Defense (DoD) uses the 5350-5470 MHz and 5850-5925 MHz frequency bands for radar systems. The band is used for multifunction anti-air warfare radars that are part of a transportable, advanced ground-based air defense missile system in support of tactical operations and training. Additionally, the bands also support the operations of new multifunction shipboard radar systems operated by both the Navy and the U.S. Coast Guard. Navy radars also use this band for surface-search and navigation functions.

These frequency bands are part of the overall frequency range known as C-Band, a principal band supporting DoD range operations. The military agencies use this frequency range extensively for test and launch range instrumentation radars to track aircraft, rockets, missiles, satellites, launched vehicles, and other targets. These radars may be either fixed or transportable systems and are typically used as the prime coverage system for range safety. Many DoD ranges use transponders in this band, operated in conjunction with the range radars, on platforms undergoing testing. The transponders provide a high degree of tracking accuracy and are critical elements of range safety.

DoD also uses these frequency bands for other systems including weather radars and a new sense and avoid radar currently under development for large UAS platforms. There are also DoD communications links that are authorized to operate in these bands. These links variously support the operations of certain mid-altitude UAS platforms, remotely operated video targeting systems, and possible future wideband maritime communications systems. Finally, these bands support Electronic Attack/Electronic Warfare (EA/EW) capabilities.

This appendix describes most of the DoD systems operating in the 5350-5470 MHz and 5850-5925 MHz bands.

UNITED STATES ARMY

Range and Tracking Radars

The Army requires accurate trajectory data of objects in the development and testing of various test objects such as missiles and rockets. The data are provided by range tracking radars and beacon transponders. These systems operate in the 5400-5900 MHz band. The range tracking radars are designed specifically to acquire and accurately track missiles (with or without beacons), nose cones, boosters, range assemblies, instrument packages, and debris and to provide trajectory data of these objects for real-time or future evaluation of performance. Target-position data from the radars also can be used to maintain range safety. Target tracking can be performed using either skin track or by the use of beacon transponders. Beacon transponders are installed on-board missiles and other test objects to enhance radar tracking of the test objects whenever the skin track signal is too weak or the tracking radar is experiencing interference. This is accomplished through the interrogation of the beacon by the tracking radar and a response (which is usually a stronger signal than the skin return) from the beacon transponder.

Weather Radars

Weather radars are used to locate precipitation, calculate its motion, and estimate its type (*i.e.*, rain, snow, hail, etc.). Modern weather radars are mostly pulse-Doppler radars, capable of detecting the motion of rain droplets in addition to the intensity of the precipitation. Both types of data can be analyzed to determine the structure of storms and their potential to cause severe weather.

Unmanned Aerial System Data Links

The Army is a major developer and user of UASs and Unmanned Aircraft (UA). A UAS includes one or more UA and associated Ground Control Stations (GCS). Medium-altitude UA that use the 5350-5470 MHz band are used to provide homeland security; drug interdiction; intelligence, surveillance, and reconnaissance; combat search and rescue; laser target designation for precision strike by manned aircraft; convoy and raid over-watch; and real-time full-motion video for target development. Test and training for all these important missions are conducted at sites in the United States.

Several UAS include a C-Band (5250-5850 MHz) data link system, the Medium Altitude Endurance Unmanned Aerial Vehicle (UAV) Line-of-Sight Command and Video Link. Data are passed on two sub-bands: 5250-5475 MHz and 5625-5850 MHz. A diplexer permits full duplex operation. Command and control information is passed from the GCS to the UA using a Command Link (CL). Payload data and status information is passed from the UA to the GCS using a Return Link (RL). The transmitter and receiver units can be software configured to perform CL or RL functions; this is useful in relaying data from one UA to another. The affected UAS data link systems utilize two CLs and two RLs.

Use of UAs for development, training, and operations in the U.S. air space is highly regulated by the Federal Aviation Administration (FAA) to ensure aircraft safety of flight. As a result of safety-of-flight concerns, the FAA has placed a number of restrictions on U.S. UAS operations.

UNITED STATES NAVY AND UNITED STATES MARINE CORPS/UNITED STATES COAST GUARD

Shipboard Navigation Radars

The shipboard navigation radar is a two dimensional (azimuth and range) pulsed radar set primarily designed for surface operations. It can also detect anti-ship missiles and low flying aircraft. The radar set operates in the 5450-5825 MHz range, using a coaxial magnetron as the transmitter output tube. The transmitter/receiver is capable of operation in several pulse width settings: long pulse (1.0 μs), medium pulse (0.25 μs), or short pulse (0.10 μs) modes to enhance radar performance for specific operational or tactical situations. Pulse Repetition Frequencies (PRFs) of 750, 1200 and 2400 pulses per second (pps) are used for the long, medium, and short pulse modes, respectively. The higher pulse repetition frequency (PRF) settings coupled with the shortest pulse increases the resolution of the radar return. Increased radar resolution enables the radar operator/observer to discern or differentiate between a single large target or two smaller targets in close proximity to each other. System performance is improved by the addition of a very narrow pulse mode (0.1 μs), providing better navigation and improved resolution of small targets at short ranges. Long and medium pulse (1 and 0.25 μs) modes are used in open sea for detection of long-range and medium-range targets. Performance is further improved by a digital video clutter suppressor and an interference suppressor. The shipboard navigation radar provides primary surface search and navigation capabilities, with limited air search capability, for the ships it is installed on. Other variations perform navigation, station keeping, and general surface search duties in addition to supporting the combat systems as shown below:

- Primary combat mission (Anti-surface Warfare)—provides a quick reaction, automated target detection and track capability
- Secondary combat mission (Anti-Air Warfare)—detects low elevation (conventional) threats.

The shipboard navigation radar set is installed on 105 U.S. Navy ships. It operates continuously during the ship's deployment, and operations depend on the ship's schedule and availability.

Shipboard Multifunction Radar #1

The Navy and the U.S. Coast Guard are developing a new shipboard radar to operate on future surface combatants. This radar is currently operating on a limited number of ships and is approved for operational use by NTIA. This radar is a shipborne multimode three dimensional (3-D) radar for surveillance and weapon assignments and is ideally suited for the light combatants providing excellent range for small Radar-Cross-Section (RCS) targets. This radar uses a phased array antenna for simultaneous detection and tracking of multiple targets and employs electronic stabilization to neutralize the rolling motion of the ship operating in choppy coastal waters. This shipboard radar provides the following modes of operation: target indication, sea skimmer, sea and air surveillance, extended range, long range surveillance, and gun fire support.

The Shipboard Multifunction Radar #1 operates continuously during the ship's deployment, based on the ship's schedule and availability, performing normal littoral patrol activities, homeland defense, Humanitarian Assistance and/or Disaster Response (HA/DR) missions, or Fleet priority tasking. Similarly, the Coast Guard uses this same radar during the cutter's deployment performing the following missions: defense readiness; drug interdiction/counter drug; other law enforcement; living marine resource; ports, waterways, and coastal security; migrant interdiction; search and rescue; and marine environmental protection.

Shipboard Multifunction Radar #2

The Navy is also developing another new shipboard radar to operate on future surface combatants. This radar is currently operating on a limited number of ships and is approved for operational use by the NTIA. This radar also is a shipborne multimode 3-D radar for surveillance and weapon assignments and is ideally suited for the light combatants providing excellent range for small radar cross section targets. This radar uses a phased array antenna for simultaneous detection and tracking of multiple targets and employs electronic stabilization to neutralize the rolling motion of the ship operating in choppy coastal waters.

Shipboard Multifunction Radar #2 functions include track-on-jam, target classification of both hovering and moving helicopters, navigation capabilities, target indication to weapon systems for precision anti-air/surface engagement, and splash spotting. It operates continuously during the ship's deployment, based on the ship's schedule and availability, performing normal littoral patrol activities, homeland defense, HA/DR missions, or Fleet priority tasking as required.

Range and Tracking Radars and Transponders

The Navy requires accurate trajectory data for flight testing of various test objects such as aircraft, missiles, and rockets. The data are provided by range tracking radars and beacon transponders. These systems operate in the 5400-5900 MHz frequency band, which overlaps the 5350-5470 and 5850-5925 MHz bands. The range tracking radars are designed specifically to acquire and accurately track missiles (with or without beacons), nose cones, boosters, range assemblies, instrument packages, and debris and to provide trajectory data of these objects for real-time or future evaluation of performance. Target-position data from the radars also can be used to maintain range safety. Target tracking can be performed using either skin track or by the use of beacon transponders. Beacon transponders are installed on-board missiles and other test objects to enhance radar tracking whenever the skin track signal is too weak or the tracking radar is experiencing interference. This is accomplished through the interrogation of the beacon by the tracking radar and a response (which is usually is a stronger signal than the skin return) from the beacon transponder.

The Navy operates numerous test and training facilities within the United States and Possessions (US&P). These facilities are equipped with several different tracking radars. The radars and transponders may be tuned to any frequency in the 5400-5900 MHz frequency band, and operate at any time as test, evaluation, and training missions dictate. The range tracking radar transmits on a fixed frequency in the allocated frequency band to skin-track targets. If the use of a beacon transponder is required, the radar transmits a coded pulse group to interrogate the beacon transponder on the missile being tracked. The beacon receiver is tuned to the radar transmit frequency and the beacon transmits a return signal to the radar.

Frequencies for the range tracking radars and beacon transponders are used during each missile system launch. As such, their use is dependent upon the number and frequency of missile flights scheduled at each test and training range. They can be used on a daily basis for test preparation and calibration, and are used continuously for the duration of each missile flight.

Other Navy Systems

The Navy has additional systems that are capable of operating over the two frequency bands under study. However, the time available for this initial effort did not allow for a technical assessment of the possible impact of sharing on these operations and systems. The Navy will need to identify and describe these systems for the follow-on detailed analysis.

UAS Data Links. The Navy is a developer and user of UAS and UA. Medium-altitude UAS that use the 5350-5470 MHz band are used to provide homeland security; drug interdiction; intelligence, surveillance, and reconnaissance; combat search and rescue; laser target designation for precision strike by manned aircraft; convoy and raid over-watch; and real-time full-motion video for target development. Test and training for all of these important missions is conducted at sites in the United States.

The Medium-altitude UAS contains a C-Band (5250-5850 MHz) data link system.[117] Data is passed on two duplexed sub-bands, 5250-5475 MHz and 5625-5850 MHz. Command and control information is passed from the GCS to the UA using the CL. Payload data and status information are passed from the UA to the GCS using the RL. The transmitter and receiver units can be software configured to perform CL or RL functions; this is useful in relaying data from one UA to another. The UAS data link system utilizes two CLs and two RLs.

SeaLancet Data Link Radio. SeaLancet is a tactical, wideband OFDM networked radio solution designed specifically to meet the demanding communications requirements of military tactical missions. This innovative, network-centric radio connects the maritime battlespace to the ground- and air-based theatre network, utilizing unique protocol and software modifications that deliver assured communications for long-range, high throughput, net-centric missions.

Compact size and high performance makes SeaLancet ideal for use on a wide range of tactical platforms in a dynamic, networked environment. The 5 GHz band is used as a command

[117] *See* S. Bonter, Y. Kim, J. Timko, and T. Luu. *Electromagnetic Compatibility Analysis of the Predator UAV Line-of-Sight Data Link Terminal with the Communications-Electronics Environment at Indian Springs Air Force Auxiliary Field*. JSC-PR-03-024. DoD Joint Spectrum Center. Annapolis, MD (November 2003) Distribution of this document is authorized to DoD Components Only; Operational Use; November 2003. Other requests for this document shall be referred to Air Combat Command UAV Special Mission Office (ACC/DR-UAV) or Joint Spectrum Center Acquisition Support Division (JSC/J8).

and control link band for unmanned aerial vehicles. Potential future use include littoral combat ship (LCS) mission modules; Extended Maritime Interdiction Operations; Tactical Ship-to-ship communications; Long Range Airborne Intelligence, Surveillance, and Reconnaissance; Pier side connectivity and coastal surveillance.

Multi-band Satellite Terminals. Multi-band satellite terminals are capable of operations in the satellite communications bands referred to as C, X, Ku, and Ka bands. The 5925-6425 MHz frequency range is the uplink, known as C-Band, for commercial Fixed Satellite services. DoD agencies, including the Navy, often lease communications capacity on commercial satellite systems operating at C-Band. The frequency range 5850-5925 MHz also has a primary allocation for commercial Fixed Satellite uplink operations; however, restrictions placed on such operations by footnote US245 have limited the development of services in the band and commercial satellite services are typically not provided. The C-Band satellite earth station receive frequencies are at 3700-4200 MHz. The earth stations have no receive function in the frequency ranges of interest (5350-5470 MHz and 5850-5925 MHz).

Weather Radars. Ground-based weather radars are used to aid flight control of aircraft or possibly tethered aerostats used for law enforcement. These radars are located near airfields and the resulting weather products are used by both the military and/or civilian airfield staff and/or the aerostat flight control staff.

Electronic Attack/Electronic Warfare. The U. S. Navy performs EA/EW training and testing in the 5350-5470 MHz and 5850-5925 MHz bands. Training operations that include these frequency bands take place in the US&P and coastal waters, are intermittent and coordinated.

UNITED STATES AIR FORCE

Range and Tracking Radars and Transponders

The U. S. Air Force (USAF) requires accurate trajectory data for flight testing of various test objects such as aircraft, missiles, and rockets. The data are provided by range tracking radars and beacon transponders. These systems operate in the 5400-5900 MHz frequency band, which overlaps the 5350-5470 and 5850-5925 MHz bands. The range tracking radars are designed specifically to acquire and accurately track missiles (with or without beacons), nose cones, boosters, range assemblies, instrument packages, and debris and to provide trajectory data of these objects for real-time or future evaluation of performance as well as for range safety of personnel and equipment. Use of target-position data from the radars is the prime means to maintain range safety. Target tracking can be performed using either skin track or by the use of beacon transponders. Beacon transponders are installed on-board missiles and other test objects to enhance radar tracking whenever the skin track signal is too weak or the tracking radar is experiencing interference. This is accomplished through the interrogation of the beacon by the tracking radar and a response (which is usually is a stronger signal than the skin return) from the beacon transponder.

The USAF operates numerous test and training facilities within the US&P. The radars and transponders may be tuned to any frequency in the 5400-5900 MHz frequency band, and operate at any time as test, evaluation, and training missions dictate. The range tracking radar transmits on a fixed frequency in the allocated frequency band to skin-track targets. If the use of a beacon transponder is required, the radar transmits a coded pulse group to interrogate the beacon transponder on the missile being tracked. The beacon receiver is tuned to the radar transmit frequency and the beacon transmits a return signal on an offset frequency within the band to the radar.

Frequencies for the range tracking radars/beacon transponders are used during each missile system launch, primarily for range safety. As such, their use is dependent upon the number and frequency of missile flights scheduled at each test and training range. They can be used on a daily basis for test preparation and calibration, and are used continuously for the duration of each missile flight.

UAS Data Links

Like the Army and Navy, the USAF is a major developer and user of UASs and UA. These systems may be used for surveillance and intelligence gathering and can support a variety of mission payloads including radars; cameras; infrared and electro-optical sensors; and electronic information gathering systems. Other federal agencies that have applications for a such a platform—for operations such as hurricane monitoring, maritime surveillance, drug interdiction, and wildfire monitoring—have systems in development or are considering such systems. In addition, the development of platforms and training of USAF UA pilots occur at several locations within the US&P. The versatility of the platform, the expanding applications, and the need for pilot training have increased the interest in sustaining these operations in the U.S.

Airborne Sense and Avoid Radars

Use of UAs for development, training, and operations in U.S. air space is highly regulated by the FAA to ensure aircraft safety of flight. As a result of safety-of-flight concerns, the FAA has placed a number of restrictions on UAS operations. The USAF and other federal agencies are seeking to expand the U.S. operations of certain UA platforms while complying with the safety concerns of the FAA. To address these concerns, the DoD is developing both ground-based and airborne Sense-And-Avoid (SAA) capabilities to be used with UA operations. Of primary concern for the frequency ranges being considered is an unmanned sense, track, and avoid radar being developed by the USAF.

The USAF request for developmental spectrum certification describes the radar as a sensor whose output is used by an on-board autonomous SAA system on the UAS. The radar is able to detect and track other aircraft in its field of view to help avoid collisions. The system is a pulsed Doppler radar that uses linear frequency modulated pulses, comparatively low peak powers, and a high PRF. The system has a forward-looking, phased array antenna with a high gain and can scan in both the vertical and horizontal planes. The 5350-5460 MHz band is the primary frequency range currently being considered in the development of this radar, while 5150-5250 MHz is being considered as an alternate.

Other USAF Systems

The USAF has additional systems that are capable of operating in the 5350-5470 MHz and 5850-5925 MHz frequency bands. However, the time available for this initial effort did not allow for a technical assessment of the possible impact of sharing on these operations and systems. The USAF will need to identify and describe these systems for the follow-on detailed analysis.

Targeting Pods. The targeting pods use the 5250-5850 MHz frequency band for downlink and uplink communication with the Remotely Operated Video Enhanced Receiver (ROVER) family of systems. This communication link allows ROVER-equipped ground units to view targeting video and receive metadata from the pods (*i.e.*, to see what the pilot is seeing), greatly enhancing weapon system effectiveness and reducing target acquisition time. Nominally, the analog downlink range is 25 miles, while the digital downlink range (at the lowest data rate) is 40 miles. For reliability and robustness these links are able to operate in frequency bands from UHF to Ku-band; operations at the frequencies of interest in this effort are on a not-to-interfere basis in the US&P since the band allocations do not support Mobile service operations on a primary, protected basis.

The targeting pods are carried on a variety of USAF and U.S. Marine Corp aircraft and are used domestically at USAF, Air National Guard, and Air Force Reserve training and testing locations. Follow-on versions of the pods are in various stages of development, and will continue to undergo qualification and operational testing at Edwards Air Force Base (AFB), Eglin AFB, and Nellis AFB during the upcoming months.

Ground Multi-band Terminal. The USAF has frequency assignments for the Ground Multi-band Terminal (GMT) at the Utah Test and Training Range in Utah. GMT terminals are capable of operations in the satellite communications bands referred to as C, X, Ku, and Ka bands. The 5925-6425 MHz frequency range is the uplink for commercial Fixed Satellite services known as C-Band and DoD agencies, including the AF, often lease communications capacity on commercial satellite systems operating at C-Band. The frequency range 5850-5925 MHz also has a primary allocation for commercial Fixed Satellite uplink operations; however, restrictions placed on such operations by footnote US245 have limited the development of services in 5850-5925 MHz band. For the frequency range of interest, the GMT does not have operations as there are no commercial satellite services in the band. The C-Band satellite receive frequencies are at 3700-4200 MHz. The terminal has no receive function in the 5350-5470 MHz and 5850-5925 MHz bands.[118]

Ground-Based Weather Radar. The ground-based weather radar is a version of the weather radar that Rockwell Collins produces for use on aircraft. The USAF has one frequency assignment for this ground-based weather radar at Fort Huachuca, AZ. The radar is used to aid in the flight control of a tethered aerostat at Fort Huachuca for law enforcement. The radar is located

[118] There is a potential interference problem to the receiver on-board the satellite. Since the military agencies only lease the service as customers, it is anticipated that the impact to the satellite receiver will be addressed by the FCC working with the commercial satellite service providers and will not be considered as part of this study.

near the airfield on Fort Huachuca and weather products are used by both the aerostat flight control staff and staff at the Army/civilian airfield.

Electronic Attack/Electronic Warfare. The USAF performs EA/EW training and testing in the 5350-5470 MHz and 5850-5925 MHz bands. Training operations that include these frequency bands take place in the US&P and coastal waters, are intermittent and coordinated.

Diagnostic Radar Systems. Diagnostic radar systems are being implemented to measure the effectiveness of aircraft low-observable (LO) materials. These systems use RCS imaging technology to identify LO defects, categorize the magnitude of the defect, and verify LO integrity across a broad range of frequencies, including both of the target 5 GHz bands. These diagnostic radar systems are used at short distances from the aircraft. Frequency assignments are in place at Whiteman AFB; Plant 42, Palmdale, California; Edwards AFB; Tyndall AFB; Holloman AFB; Nellis AFB; Hill AFB; Eglin AFB; and Langley AFB.

APPENDIX D

DESCRIPTION OF DEDICATED SHORT-RANGE COMMUNICATION SERVICE SYSTEMS OPERATING IN THE 5850-5925 MHZ BAND

INTRODUCTION

The appendix provides a description and technical parameters for the Intelligent Transportation System Dedicated Short-Range Communications Service (DSRCS) systems operating in the 5850-5925 MHz band.

DSRCS SYSTEM DESCRIPTION

The DSRCS Road Side Units (RSUs) are authorized under Part 90 (Section 90.7) of the Federal Communications Commission (FCC) rules. The On-Board Units (OBUs) are authorized under Part 95 (Subpart L) of the FCC rules. The information in this appendix comes from the Institute of Electrical and Electronics Engineers (IEEE) Standard for Information technology – Telecommunications and information exchange between systems – Local and metropolitan area networks – Specific requirements, Part 11: Wireless Local Area Network (LAN) Medium Access Control (MAC) and Physical Layer (PHY) Specifications and will be referred to as the IEEE 802.11p standard. Other information is contained in the rules and regulations set forth by the Federal Communications Commission.

The modulation used for DSRCS is OFDM. Figure D-1 provides a simple block diagram for a transmitter and receiver.

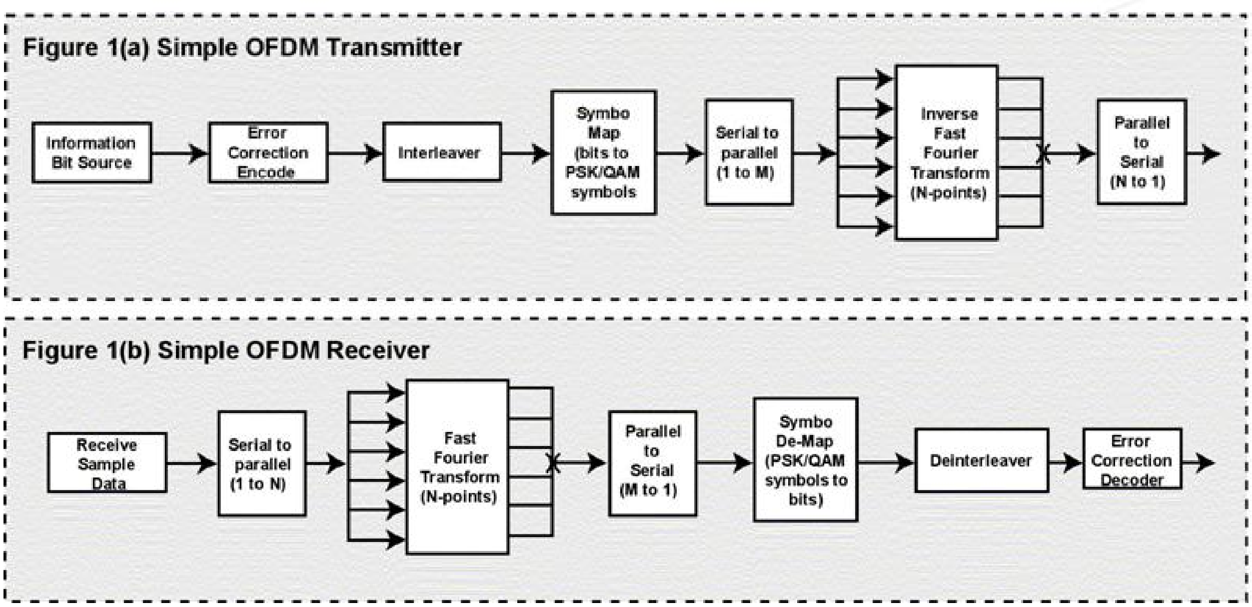

Figure D-1. DSRCS Transmitter and Receiver

The transmitter and receiver technical characteristics for DSRCS systems are provided in Table D-1 through D-4.

Table D-1. Transmitter Characteristics

<table>
<tr><th>Parameter</th><th colspan="2">Value</th></tr>
<tr><td>Emission 3 dB Bandwidth (MHz)</td><td colspan="2">10 or 20</td></tr>
<tr><td>Power (Peak) (dBm)</td><td colspan="2">23 to 44.8 (Depending on RSU or OBU and Channel used)</td></tr>
<tr><td rowspan="2">Emission Spectrum
(Relative Attenuation (dB) as a Function of Frequency Offset from Center Frequency (ΔF) (MHz))</td><td>Attenuation</td><td>ΔF</td></tr>
<tr><td>See Note a</td><td>See Note a</td></tr>
<tr><td>Antenna Gain (Main beam) (dBi)</td><td colspan="2">3 to 15 typical</td></tr>
<tr><td>Azimuth Off-Axis Antenna Pattern
(dBi as a function of off-axis angle in degrees)</td><td colspan="2">Omni is typical; sectorized antennas sometimes used with 65 to 90 deg at 3dB for Infrastructure DSRCS transmitter antennas</td></tr>
<tr><td>Elevation Off-Axis Antenna Pattern
(dBi as a function of off-axis angle in degrees)</td><td colspan="2">Typical 3 to 15 dB with 3dB point at 15 to 35 deg.</td></tr>
<tr><td>Antenna Height (meters)</td><td colspan="2">1.5-15[b]</td></tr>
<tr><td>Antenna Polarization</td><td colspan="2">Primarily vertical (some dual linear polarized)</td></tr>
<tr><td>Antenna Azimuth 3 dB Beamwidth (degrees)</td><td colspan="2">Normally Omni for infrastructure and vehicle; Infrastructure Sectorized antennas man be 65 to 90 deg</td></tr>
<tr><td>Cable, Insertion, or Other Losses (dB)</td><td colspan="2">1 to 3 dB typical. (Function of installation and materials used)</td></tr>
<tr><td colspan="3">Note a: Spectrum mask for 10 MHz channels, the transmitted spectral density shall have a 0 dBr bandwidth not exceeding 9 MHz and shall not exceed the spectrum mask created using the permitted power spectral density levels listed in Table D-2.

Note b: A RSU may employ an antenna with a height exceeding 8 meters but not exceeding 15 meters provided the EIRP specified in the table below is reduced by a factor of 20 log(Ht/8) in dB where Ht is the height of the radiation center of the antenna in meters above the roadway bed surface. The EIRP is measured as the maximum EIRP toward the horizon or horizontal, whichever is greater, of the gain associated with the main or center of the transmission beam. The RSU antenna height shall not exceed 15 meters above the roadway bed surface.</td></tr>
</table>

Table D-2. Transmitter Power Spectral Density

Transmit Power Class	Permitted Power Spectral Density (dBr)				
	± 4.5 MHz offset (±f1)	± 5.0 MHz offset (±f2)	± 5.5 MHz offset (±f3)	± 10 MHz offset (±f4)	± 15 MHz offset (±f5)
Class A	0	–10	–20	–28	–40
Class B	0	–16	–20	–28	–40
Class C	0	–26	–32	–40	–50
Class D	0	–35	–45	–55	–65

Table D-3. Receiver Characteristics

Parameter	Value	
Receiver 3 dB Intermediate Frequency (IF) Bandwidth (MHz)	Not Applicable to OFDM Receiver; direct conversion to baseband	
Receiver IF Selectivity (Relative Attenuation (dB) as a Function of Frequency Offset (MHz))	**Attenuation**	**ΔF**
	See Table D-4	See Table D-4
Noise Figure (dB)	5 to 15 ; 10 typical	
Antenna Gain (Main beam) (dBi)	3 to 15 typical	
Azimuth Off-Axis Antenna Pattern (dBi as a function of off-axis angle in degrees)	Omni is typical; sectorized antennas sometimes used with 65 to 90 deg at 3dB for Infrastructure DSRCS transmitter antennas	
Elevation Off-Axis Antenna Pattern (dB as a function of off-axis angle in degrees)	Typical 3 to 15 dB gain with 3dB point at 15 to 35 deg.	
Antenna Polarization	Typically Vertical; some dual linear	
Antenna Height (meters)	1.5 to 15	
Antenna Azimuth 3 dB Beamwidth (degrees)	Typically omni; may be 65 to 90 deg at 3dB for infrastructure sectorized antenna	
Cable, Insertion, or Other Losses (dB)	Function of installation, transmission cable type/length and connector/coupler loss; typically 1 to 3 dB; typical value is 2 dB	

Table D-4. Receiver Selectivity

Data Rate (Megabits Per Second)	Adjacent Channel Rejection (dB)	Alternate Adjacent Channel Rejection (dB)
3	28	42
4.5	27	41
6	25	39
9	23	37
12	20	34
18	16	30
24	12	26
27	11	25

APPENDIX E

ACRONYMS AND ABBREVIATIONS

A	Activity Rate
AFB	Air Force Base
AIFS	Arbitration Innerframe Space
AP	Access Point
ASTM	American Society for Testing and Materials
BE	Best effort
BK	Background
BSS	Basic Service Set
BW	Bandwidth
C.F.R.	Code of Federal Regulations
CL	Command Link
dB	Decibel
dBi	Decibel Isotropic
dBm	Power ratio in decibels of the measured power to one milliwatt
dBr	Decibel reference
DFS	Dynamic Frequency Selection
DoD	Department of Defense
DOT	Department of Transportation
DSRCS	Dedicated Short Range Communication Service
EA/EW	Electronic Attack/Electronic Warfare
EDCA	Enhanced Distributed Channel Access
EIRP	Equivalent Isotropically Radiated Power
EMC	Electromagnetic Compatibility
FAA	Federal Aviation Administration
FCC	Federal Communications Commission
GCS	Ground Control Station
GHz	Gigahertz
GMT	Ground Multi-band Terminal
HA/DR	Humanitarian Assistance and/or Disaster Response
Ht	Height
IEEE	Institute for Electrical and Electronics Engineers
IF	Intermediate Frequency
IFS	Innerframe Space
ISM	Industrial, Scientific and Medical
ITU-R	International Telecommunication Union-Radiocommunication Sector
JTG	Joint Task Group
kHz	Kilohertz
km	Kilometers
LAN	Local Area Network
LO	low-observable
M	Market Penetration
m	Meters
MAC	Medium Access Control Layer
MCS	Modulation, coding, and spatial streams
MHz	Megahertz
msec	Microsecond

mW	Milliwatts
NASA	National Aeronautics and Space Administration
NHTSA	National Highway Traffic Safety Administration
NTIA	National Telecommunications and Information Administration
OBU	Onboard Unit
OFDM	Orthogonal Frequency Division Multiplexing
P	Total Population
P_E	Population Environment
P_D	Population Distribution
PDF	Probability Density Function
PHY	Physical Machine Layer
PLCP	Physical Layer Conversion Protocol
PPDU	PLCP Protocol Data Unit
PPS	Pulses per Second
PRF	Pulse Repetition Frequency
POC	Probability of Coincidence
PSK	Phased Shift Keying
QAM	Quadrature Amplitude Modulation
RADARSAT	Radar Satellite
RCS	Radar-Cross-Section
RF	Radio Frequency
RL	Return Link
RLAN	Radio Local Area Network
ROVER	Remotely Operated Video Enhanced Receiver
RSU	Road Side Unit
S	System Factor
SAA	Sense-And-Avoid
SAR	Synthetic Aperture Radar
SS	Spatial Streams
TCP	Transmission Control Protocol
TDWR	Terminal Doppler Weather Radar
TPC	Transmitter Power Control
TVBD	Television Band Device
TXOP	Transmit Opportunity
UA	Unmanned Aircraft
UAS	Unmanned Aircraft Systems
UAV	Unmanned Aerial Vehicle
U-NII	Unlicensed-National Information Infrastructure
U	Uniform
U	Users
U.S.	United States
US&P	United States and Possessions
µsec	Microsecond
VI	Video
VO	Voice
W	Watt
WAS	Wireless Access Systems
Wi-Fi	Wireless-Fidelity
WRC-03	World Radiocommunication Conference 2003
WRC-15	World Radiocommunication Conference 2015